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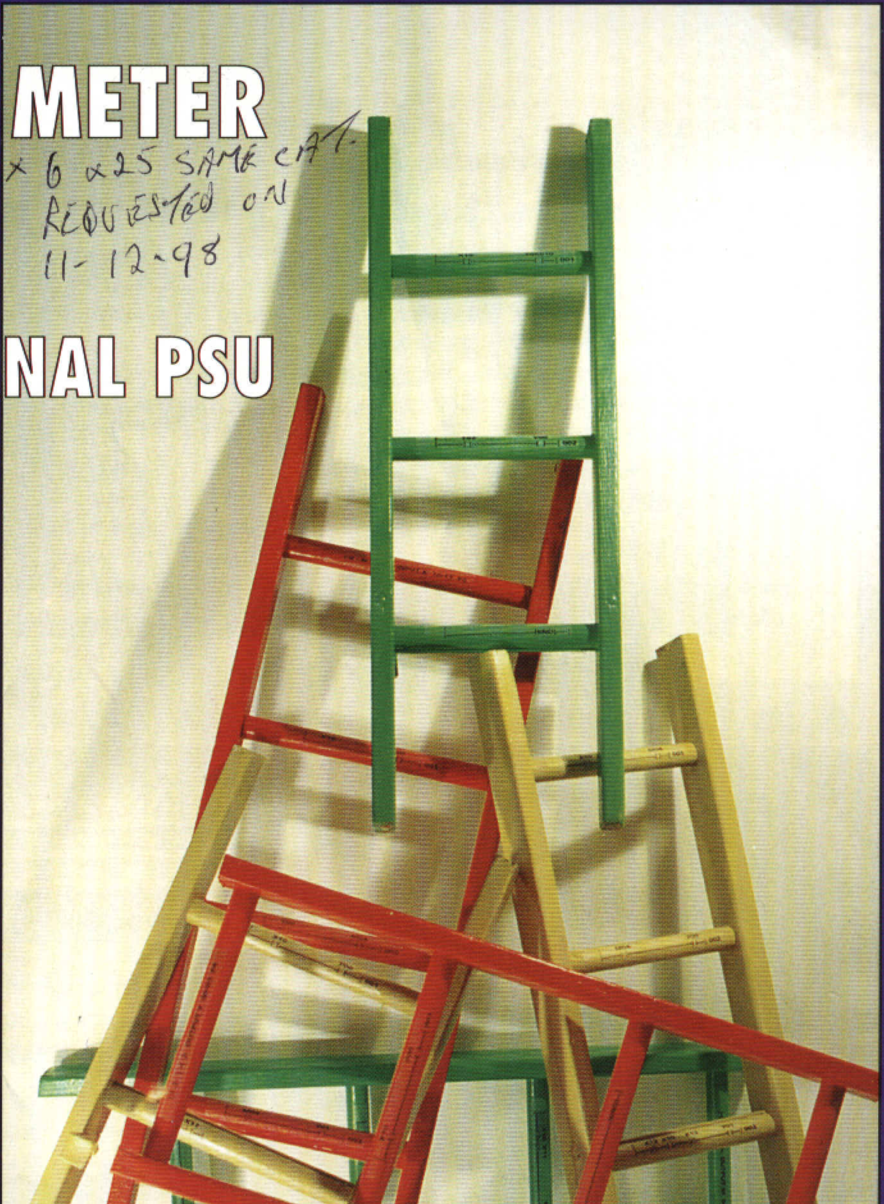

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Electronics and Computing • Projects for the Future

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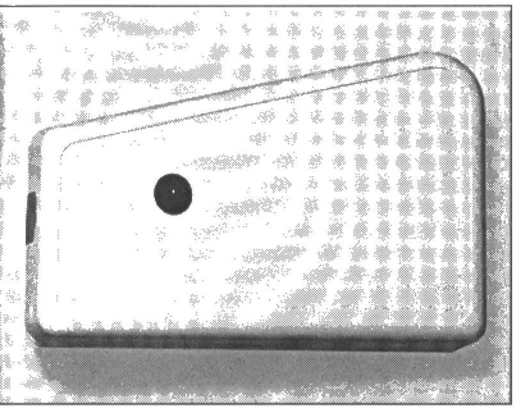
Programmable Logic Controllers and Ladder Logic 10

Programmable logic controllers are in effect dedicated computers designed to control networks of relays in automated machinery. The specialised programming language is can be downloaded from a PC, and looks disarmingly like an ordinary schematic. Stephen Fleetham explains the difference.

A Microcontroller-Based Programmable Logic Controller 16

This logic controller and interface board designed by Stephen Fleetham provide a practical means to trying some of the principles in the Ladder Logic feature in this issue.



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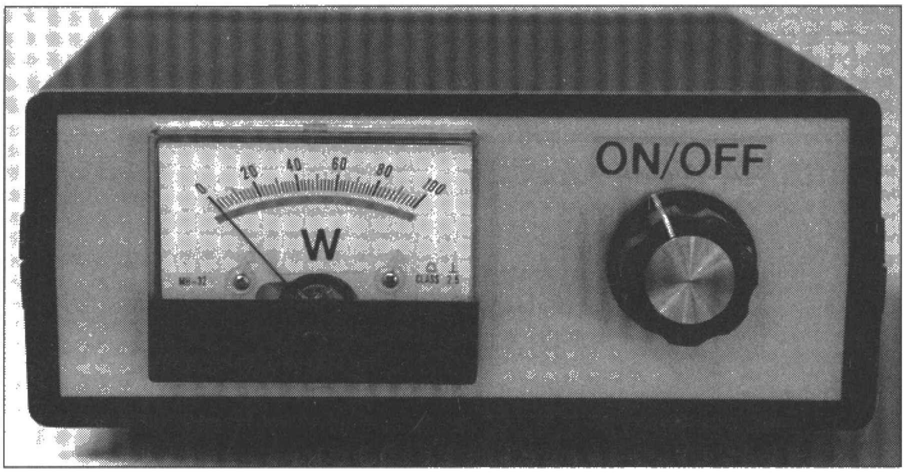

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Robert Penfold's audio meter measures actual power, rather than volt-amperes. Designed to measure audio power delivered to a loudspeaker, it can measure ac (or dc) power over a range wider than the audio frequency band.

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Bob Noyes's Car Vigilante watches for traffic approaching from the rear when your car is parked and switches on your parking lights (or extra parking lights) to give your car added visibility.

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For special timing requirements there is scope for designing and building your own system. Owen Bishop has designed an example of a practical timing circuit using techniques described in this series to boost a home security system and other process control applications.

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Europe's premier model show is coming to Olympia immediately after Christmas.

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The alignment of radio receivers can be optimised with Raymond Haigh's low-cost unit which enables the radio's IF response to be displayed on an oscilloscope screen.

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This small surface-mount switched mode power supply was designed with the Wobbulator in mind, but it has many other applications. It is a cheaper alternative to PP3s as an internal power supply for most battery-powered projects.

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Tony Sercombe's audio millivoltmeter is designed to read AC signals accurately over the audio range. It has six ranges and reads up to 50kHz.

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ETI ELECTRONICS TODAY INTERNATIONAL News...

RSGB/RA Young Amateur of the Year Winners

Winner old Mark Shepherd M0AGQ/G7WHL from Brighton

Photos Courtesy of the RSGB

The winner of the 1998 Young Amateur of the Year Award is 17-year-old Mark Shepherd M0AGQ/G7WHL from Brighton.

The Young Amateur of the Year Award is organised jointly by the Radio Society of Great Britain and the Radiocommunications Agency and aims to encouage young people to take up and further their interest in amateur radio.

Mark is involved with the organisation of the amateur radio club at his school and its emergence as a bona fide radio club in 1996. He has been Secretary of the club for the last three years. Among the events he has organised this year are contests such as IOTA (Island on the Air) and special events stations. He has also staged electronics and radio displays which have resulted in several pupils joining the club. Having combined all this with his A level studies, Mark continues with revision classes for the RAE (Radio Amateurs' Examination) and priactice Morse lessons. A particular interest is packet radio, and Mark has spent a great deal of time and effort developing as a sysop and running a bulletin board station (BBS).

Mark was presented with the first prize of £300 by the RA's director of Spectrum Services, Hazel Canter, at the RSGB's annual HF Convention at Windsor in October. He also received a certificat signed by Peter Mandelson, Secretary of State for Trade and Industry, and will be invited to the RA's Radio Monitoring Centre at Baldock, Herts, for the traditional conducted tour.

The worthy runner up is 16-year-old Peter Evans M0BOO from Orpington, Kent. Peter is a keen and active member of two clubs, of one of which he is a founder member and Chairman. He is a qualified Novice insntructor and has recently facilitated one to one Morse tutoring during his school lunch breaks. ETI is glad to hear that Peter is also a keen "homebrew" constructor, building receivers and antennas.

Peter received a £50 cheque from the RA and will also be invited to visit the Baldock Monitoring Station. He was also presented with an Icom IC-T22E 144 MHz FM handheld transceiver, donated by Icom (UK) Ltd.

Dale Blackman, marketing manager at Icom, said "The Young Amateur of the Year Award is very important to us as it brings together the ham enthusiasts of the future."

Runner up Peter Evans M0BOO from Orpington

Photos Courtesy of the RSGB

The Young Amateur of the Year Award is announced in the spring of each year and is normally open to any resident of the UK, Channel Islands or the Isle of Man who had not reached his or her 18th birthday by the 31st July of the previous year. Applicants must demonstrate an interest in some of the following:

- Construction of radio equipment, good operating skills, use of radio to help in the community; and
- Encouragement of others and involvement in a school or scientific project involving radio.

For further information please contact The Radio Society of Great Britain, Lambda House, Cranbourne Road, Potters Bar, Herts EN6 3JE. Tel 01707 659015.

ETI ELECTRONICS TODAY INTERNATIONAL

News...

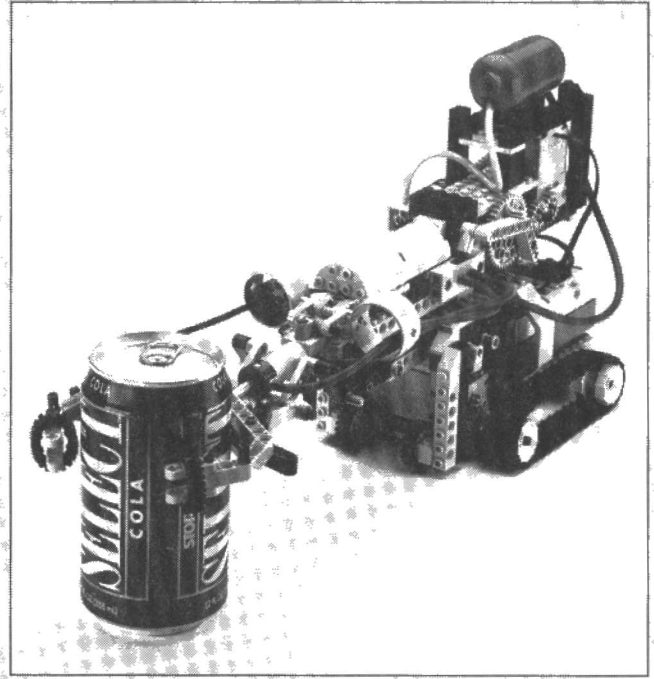
Lego Bricks Hook Up With PCs for Robot Development Kit

Classic construction toy company Lego have invented a programmable building brick.

At the heart of the new Lego Mindstorms Robotics Invention System is the RCX, a special Lego brick embedded with an 8-bit microprocessor that accepts programs downloaded from a PC. The processor also has 16K of rom, 512 bytes of internal sram and 32K of external sram, and talks to the PC via a serial port. The RCX Microcomputer has its own CD-rom based RCX Code, a user-friendly programming language designed to create programs to drive mini-robots built using the Mindstorms robotics pack.

Lego call the Mindstorms system "the challenge of the future for 12- to 14-year-olds", but the 700-piece Robotics Invention System is likely to attract the attention of more senior users, perhaps taking the time-honoured place of the model railway set as the ideal Christmas present for the kids to watch Dad play with.

The 700-piece set includes two motors, light- and touch-sensors, and building parts including mechanisms, gears and wheels. It can also incorporate parts from the existing Lego Technics series, including the hydraulics employed in the cola-can lifting mobile robot arm shown in the photograph.



The RCX Lego microcomputer with two motors, two touch sensors and a light sensor

New owners of the Robotics Invention System also get a "constructopaedia" building guide with suggestions on how to build modules and achieve various effects. These will not be the "complete building plans" included with earlier Lego sets. Achieving a complete model will be "all part of the challenge" to the inventors.

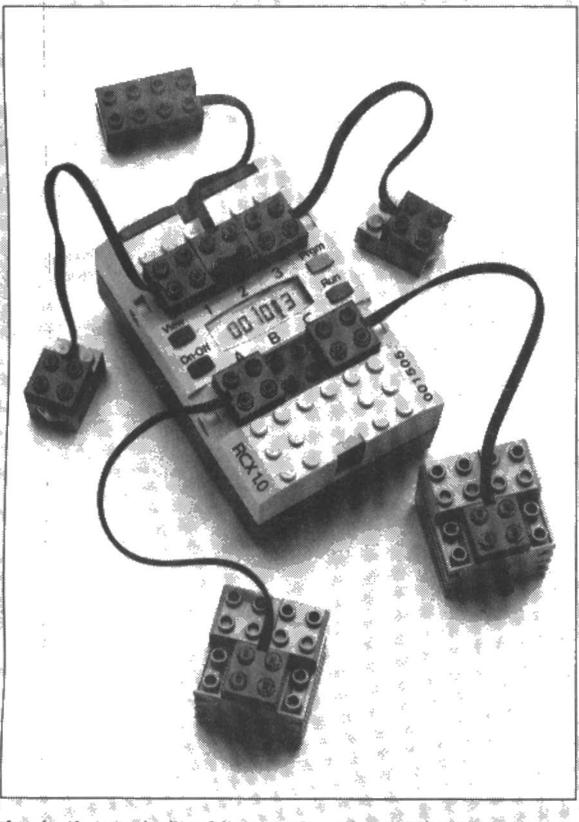
However, to assist in their quest for new ideas, new owners will automatically become members of the Mindstorms Internet community, based at the website www.LEGOMINDSTORMS.com, where users can create personal homepages, upload programs, display their inventions, talk to other users and consult Lego experts from Lego via chat rooms and message boards. Each user will receive a Robotoics Network membership with their set, with an exclusive number to log on to the website for the first time. The website will present new robot-building challenges which can downloaded.

The Mindstorms system is the result of co-operation with the Media Lab at the Massachsetts Institute of Technology (MIT), already famous for its walking robots (see The Robobugs of MIT in ETI December 1996).

Expansion sets including Robo-Sports and Extreme Creatures should be available before the end of the year.

To run the complete system, you need a minimum Pentium 90MHz processor, Windows 95, 50 MB hard disk space, a CD-rom drive, 16 MB of ram and VGA display (256 colours) and preferably a Soundblaster sound card or compatible.

For information about stores selling or displaying Lego Mindstorms, contact 0845 606 2043. They can also answer questions about computer compatibility, or pass you to someone who has more detailed information.



A robotic arm built with parts from Lego Mindstorms and Lego Technics

ETI ELECTRONICS TODAY INTERNATIONAL

News...

Vintage Valves Meet The Age Of The Internet

Large scale integration may get larger and micro fabrication may get smaller, but valves have not lost all their fascination in the age of the Internet. Record-breaking student Ed Ross has probably the largest collection of radio and TV values in the country. 18-year-old Ed, who comes from Shewsbury, has at least 3,000 valves and pursues every avenue, from local second-hand shops to the Internet, for information and contacts to keep his collection growing.

It seems that Ed is not the only collector who places a value on valves. Dr. Donald Klipstein, of a magnetics research company near the city of Philadelphia in the USA, has his own valve museum. Ed and Dr. Klipstein made international contact via the Internet, and Ed's name now appears on a brass plaque in the museum, thanking him for a donation of rare valves.

Ed says that his passion for valves was sparked off by his father's own collection of vintage radios, and followed up by reading electronics magazines. Keeping his feet firmly both in the past and the future, Ed is now studying on a three-year Network Information Management course at Bradford University. He's also staying practical by working on the design of a Theramin, based on five valves and two aerials, for a guitarist friend. No hoarder is he: "My collection is functional. The valves are all there to be used or sold," he says.

Squires Model and Craft Tool Catalogue Now Out

This is a catalogue intended mainly for model builders, but that does not preent it from containing a good range of electronic components. There are no surface mount components, and no power mosfets, or indeed fets of any description, but most other types of electronic components are represented.

Of course, many electronics projects need more than just electronic components, and this catalogue will be helpful there. If you want an electric motor and some sort of mechanical drive to agitate a pcb etching tray, this is one place to try.

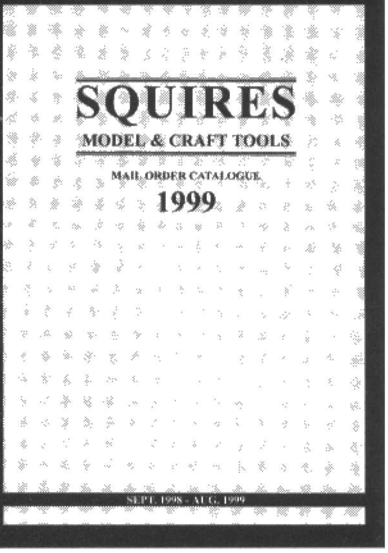
There are tools such as cutting discs, micrometers, more files and abrasives than I have seen before. In the materials section there are plastic sections (such as U channel), metal rods and bars, brass wire, and other items useful for the non-electronic parts of a project.

The catalogue has some components which are not very widely available, such as tuning capacitors and solar panels. There are also a couple of bench drills which look as if they might be ideal for drilling printed circuit boards.

Although you would need to look elsewhere for specialised ics, mosfets and all surface mount components, there is a wide enough range of electronic components for many normal projects. There is also a range of cases, electronic and mechanical tools, and other items to make the rest of the project easier.

This is a very useful catalogue, and reading through it may well make you think of an interesting project or two.

Fpr a copy of the catalogue and further information contact Squires Model and Craft Tools, 100 London Road, Bognor Regis, West Sussex PO21 1DD. Tel. 01243 842424 Fax 01243 842525.



SQUIRES
MODEL & CRAFT TOOLS
MAIL ORDER CATALOGUE
1999
SEPT. 1998 - AUG. 1999

ETI ELECTRONICS TODAY INTERNATIONAL

News...

Vann Draper Market Grundig Instrument Range in the UK and Ireland

Van Draper Electronics has signed an agreement with Grundig Test and Measuring System in Germany to market Grundig's products in the UK and the Republic of Ireland. This will make Van Draper the prime UK source for the Grundig instrument range, previously no directly available in the UK.

Van Draper has marketed its own range of general purpose instruments since 1990, and also provides a list of high quality instruments from a number of other sources including the full Kenwood range.

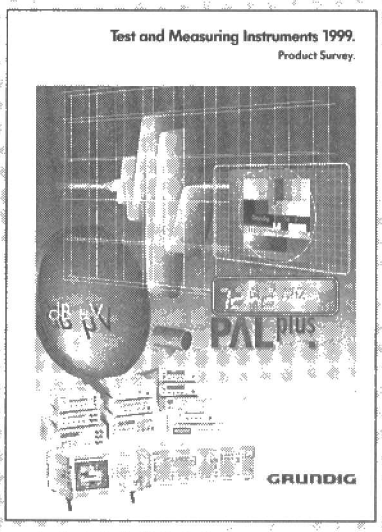
The Grundig range comes in three categories:

Laboratory and Service Measuring Instruments: including power supplies, function generators, sine wave and arbitrary generators, universal counters, LF and RF millivoltmeters, digital multimeters, automatic LCR meters and oscilloscopes, with emphasis on micorprocessor control, RS232 and IEEE interfaces.

Video Measuring Instruments: including PALplus studio encoders/decoders, video generators, terrestrial and satellite TV generators and monitor testers.

Antenna Measuring Instruments: including combination measuring receivers, antenna measuring receivers, satellite measuring receivers plus level and noise measuring instruments.

For more information on the Grundig lines and other products in the Vann Draper range please contact Vann Draper Electronics Ltd., Unit 5, Canal St., South Wigston, Leicester LE18 2PL. Tel 1006 2771400 Fax 0116 2773945. Email sales@vanndraper.co.uk Web www.vanndraper.co.uk.


Test and Measuring Instruments 1999.
Product Survey.

Motorists Rely More Upon Traffic Warning Systems For Journey Planning

A detailed survey of its members carried out by the RAD (Royal Automobile Club) revealed that motorists change their journey plans when given access to relevant, real-time travel information. The survey showed that motorists consider alternative routes, times and even modes of transport if provided with information sufficiently in advance of their journey.

The research is related to the continued expansion of the RAC's Traffic Alert 1210 telephone-based traffic information service. Four key groups of travellers were identified, and the differetn ways in which they use information provided by traffic information services. The information offered includes journey delay times, incident and roadwork information and alternative route planning. The four groups are:

- Motorway commuters: high level of local road knowledge. Journey time is critical, and traffic information is used to avoid short term delays and make informed decisions about alternative routes.

- Motorway business travellers: regular motorway users with limited local road knowledge. Use advance information to plan routes and journey times, reinforced with an in-car unit during the journey.

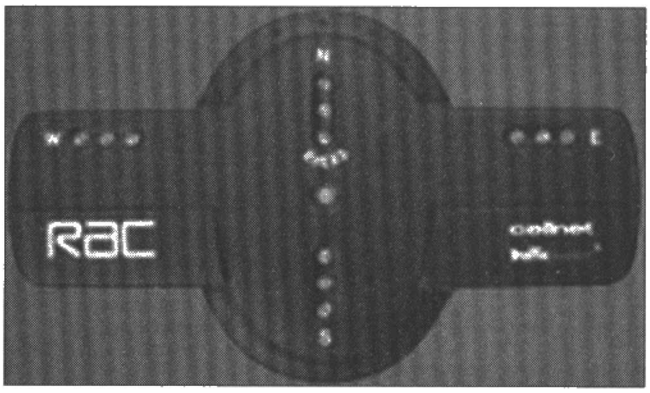
- Anxious motorway users: travel infrequently and dislike motorway journeys. Use in-car congestion warning devices to provide advance information about hold-ups, and adjust their driving accordingly.

- Trunk road users: rarely use motorways. Require regular local traffic and travel information for local roads. Trafficmaster's trunk road sensor network will be launched in late 1998 and will be linked to the RAC's Traffic Alert 1210.

RAC's Managing Director of Membership Findlay Caldwell says "More than 1.2 million drivers are caught in congestion on British motorways every day. The research ahs shown that, given timely and relevant information, travellers do reconsider journey plans and change them if appropriate."

For more information on the RAC and RAC Traffic Alert phone 0990 722722.

More motorists are turning to various phone-based and in-car traffic warning systems as congestion resulting from accidents and other incidents traps more motorists in static motorway queues without warning from traffic authorities.



ETI
ELECTRONICS
TODAY INTERNATIONAL

News...

Changes to the 10GHz Amateur Band In February 1999

The Radiocommunications Agency has announced the date for future change to the 10 GHz amateur radio band. Part of the band will be withdrawn, but there will be a small overall increase in the spectrum allocation for amateurs.

The current allocations is:
10.00 - 10.15 GHz and 10.30 - 10.50 GHz for the terrestrial service
10.45 - 10.50 GHz for the amateur satellite service
From 1 February 1998, the allocation will be:
10.00 - 10.125 GHz and 10.225 - 10.475 GHz for the terrestrial service

The amateur satellite allocation will remain unchanged.

The Agency states that it will continue to balance the needs of radio amateurs with regard to this part of the spectrum with the demands of new and existing radio services. The Agency has recently introduced an allocation at 136 kHz for amateurs.

For further information, contact the RA's public enquiry line on 1071 211 0211 (textphone 0171 215 6740 for people with hearing impairment).

Extended Frequencies for Low Power Devices

New and extended frequency allocations for Low Power Devices exempt from licensing have been announced by the Radiocommunications Agency. The current frequency allocation of 433.72 - 434.12 MHz will be extended to 433.05 - 434.79 MHz. The limitation of its use to Vehicle Radio Activated Key Entry Systems will be relaxed to accommodate General Telemetry and Telecommand applications. Audio, speech or music is not permitted in this band. Equipment must be Type Approved to ETSI specification EN 300 220-1, as recommended in the CEPT/ERC recommendation 70-03. Maximum power will be 10mW.

Controversy has previously arisen in connection with this band when it was found that legitimate Amateur Radio transmissions were capable of interfering with Vehicle Entry Systems. In some cases users were locked out of their cars, or vehicles immobilised, a considerable problem to car manufacturers providing radio activated entry systems. The ultimate origin of the allocation of an Amateur band to vehicle entry systems has not been published. However, the provisions for the extended band state clearly that "Manufacturers will be required to make it clear to potential customers that equipment may suffer interference from other legal users of this band, such as the Radio Amateurs, and will not be protected from such interference. The onus will be on the manufacture to produce equipment to an adequate standard."

The current frequency allocatation of 863.00 - 864.00 MHz for Cordless Audio Equipment will be extended to 865.00 MHz. Equipment must be Type Approved to the ETSI Specification EN 300 220-1 until ETSI publish a suitable product standard. Maximum power will be 10mW.

A new frequency allocation of 868.00 - 870.00 MHz has been made for General Telemetry and Telecommand applications. Equipment must be Type Approved to the ETSI specification EN 300 220-1. The band is split into sub-bands, and the maximum radiated power permitted will depend on the specific sub-band in use. RA information sheet RA114 Annex 3 summarises the relevant information.

The current frequency allocation of 2.400 - 2.483 GHz will be opened to General Telemetry and Telecommand applications including Visual Image Transmission Equipment. Equipment must be Type Approved to the ETSI specification I-ETS 300 440. For VITE the maximum permitted bandwidth will be 20 MH. Maximum power will be 10mW. The band will continue to be shared with other applications. The Specification remains ETS 300 328.

The relevant Licence Exemption Statutory Instrument will be amended later this year. Users may operate type approved equipment which complies with the relevant standard in the appropriate frequency band. Users are being invited to apply for a licence from the Technology Sectors Unit (Low Power Section), which will be issued free until the new Statutory Instrument is in place.

The updated allocations harmonise the UK with the rest of Europe and were applied from 31 August.

For further information contact the Radiocommunications Agency, Technology Sectors Unit (Low Power Section) Tel. 0171 211 0153.

OVERSEAS READERS

To call UK telephone numbers, replace the initial 0 with your local overseas access code plus the digits 44.

Programmable Logic Controllers and Ladder Logic

Programmable logic controllers are a hardware means of controlling machinery by a circuit-like programming language that can be programmed through an interface from a PC. Ladder diagrams look disarmingly like ordinary schematics, but they are no such thing ...

Stephen Fleetham

Once upon a time, ladder diagrams were produced to specify the hard wiring of **relay control circuits**. Despite a sometimes confusing resemblance, the meaning of the symbols used to represent the relay contacts and coils differed from those used in electronics everywhere else, with a set of normally open contacts, for example, being drawn very much the same as a capacitor. This notation could be seen as a primitive form of a diagrammatic programming interface. This may have come about because Boolean algebra was not so accessible to the people (usually electricians) who had to program these systems (by wiring them up). Consequently, the approach to designing these systems may seem unfamiliar to readers more comfortable with Boolean algebra, Next State tables and so on.

However, as hard-wiring changes required significant costly re-work, a more flexible approach was obviously needed. Consequently, Programmable Logic Controllers and relay ladder logic were developed. These were evolved from the original relay ladder logic used to implement industrial control schemes, using relays to implement compound and sequential functions.

Control functions could now be implemented and changed in software rather than in hardware rewiring. The Programmable Logic Controller now provided the electrical-electronic interface between the field devices and the relay ladder-control software.

History

The transition from hard-wired logic to Programmable Logic Controllers did not happen overnight, and what follows is a brief history of this evolution.

To the industrial manufactures supplying the relay-based control equipment, it was obvious there was a need to develop a more flexible and adaptive control philosophy. The first products to result were hybrid systems, with the individual logic elements AND, OR, TIMER, COUNTER, SHIFT REGISTER etc. assembled into small hardware modules about the size of a pack of playing cards, with all the electrical connections brought out to pins on the base of the module.

The first step in design was to draw up control schemes. These allowed the necessary logic blocks to be determined. The logic blocks were then mounted in a rack and the electrical connections made by wire-wrapping the relevant pins together.

As the technology advanced, further logic was developed. Probably the most important was the Sequencer, a means of controlling the flow of logic sequentially by a program stored in eprom memory.

The next stage in the evolution of the modern Programmable Controller was to incorporate all these logic elements into one module and control it with software.

Initially these controllers were very large, consisting of a rack housing the backplane, power supply, central processing unit (CPU), memory (magnetic core in the earliest units) and all of the input-output modules.

All that now remained was a means of programming the processor memory. This was accomplished using a hand-held programmer consisting of a keypad and LEDs. Mnemonics were used to represent the basic ladder instructions. These early devices were sometimes difficult to use and restricted in what they could achieve.

The technology developed rapidly over the years to what we have today, Programmable Logic Controllers that are physically compact (often around the size of an ordinary PC), have a rich and powerful instruction set, allow networking, support intelligent operator interfaces, and so on.

The future

Over the years Programmable Logic Control technology has rapidly developed, to the extent that high level languages such as C may be used as the preferred programming language. At the same time, PC technology has been developing in the opposite direction, becoming increasingly rugged and suitable for operation on the shop floor.

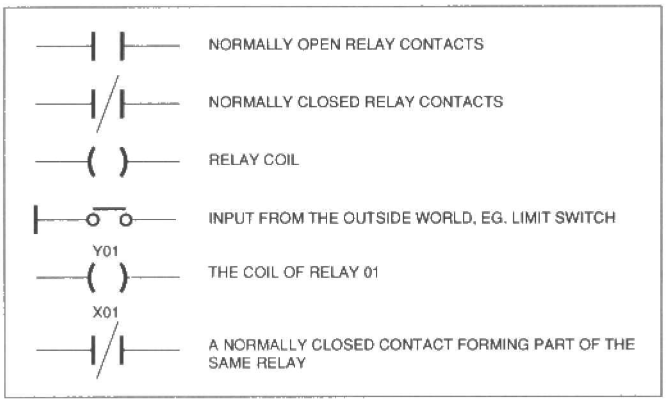
Clearly these two technologies have the potential to combine and merge, providing processing and control platforms that could only be dreamed of several years ago.

The future may well produce intelligent sensors with a 'PLC on a chip', providing parallel distributed processing, and allowing the sensor to provide the primary control function.

The symbols

As noted above, the symbols used in ladder logic have quite different meanings from those used in normal electronics. See **figure 1**. Relay parts are numbered using a convention where Yxx refers to an input, and Xxx to an output.

Figure 1: a key to ladder logic symbols used in this article


NORMALLY OPEN RELAY CONTACTS
NORMALLY CLOSED RELAY CONTACTS
RELAY COIL
INPUT FROM THE OUTSIDE WORLD, EG. LIMIT SWITCH
Y01
THE COIL OF RELAY 01
X01
A NORMALLY CLOSED CONTACT FORMING PART OF THE SAME RELAY

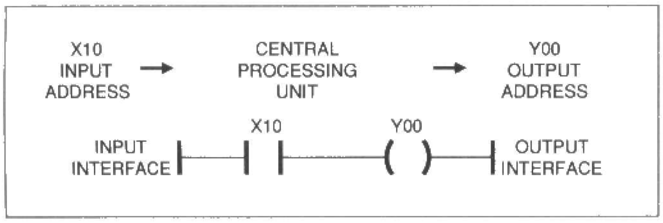
This notation originated from a time when control panels were wired up using relay logic. Nowadays the relay is used as a logic symbol for this sort of control programming, in effect a graphical method to input Boolean algebra. In principle, at least, control functions specified in this way could be executed by a box full of clattering relays instead of by a processor.

How it works

A Programmable Logic Controller is made up of the following parts (see **figure 2**):

A central processing unit
A program memory
Input interface
An output interface

Figure 2: the internal functioning of a programmable logic controller



A typical Programmable Logic Controller

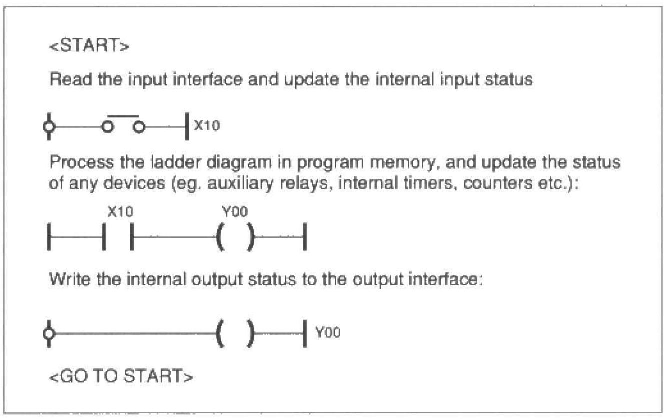
Controller operation is reasonably straightforward, and most operate on a scan basis. This is in contrast to the approach used in other types of controller, where interrupts may be used to make the unit respond to changes on inputs. A scan based system cannot cope with events which require a response in a shorter time than one complete pass through the program. This is unlikely to pose a problem when the item being controlled is mechanical.

At the start of the scan the inputs are read and the internal input status is updated. The central processing unit now reads the relay ladder program from memory and executes the instructions. Internal devices (internal relays etc.) are updated as the scan continues.

At the end of a scan, all program instructions will have been executed. This is the point at which the outputs are refreshed or updated to reflect any changes brought about by a change in input status. See **figure 3**.

For example:

Figure 3: a single scan of the Programmable Logic Controller


<START>

Read the input interface and update the internal input status

Process the ladder diagram in program memory, and update the status of any devices (eg. auxiliary relays, internal timers, counters etc.):

Write the internal output status to the output interface:

<GO TO START>

The central processing unit and memory are the heart of any Programmable Logic Controller, as it is here the program instructions are read from memory and then executed. All the processing and control is undertaken here. There are a number of different types of memory available. Most current controllers use random access memory (ram).

This type of memory is volatile. If the power is removed, the memory contents are lost. To prevent this, controllers employ a battery to take over automatically if the supply is switched off, allowing the memory contents to be retained.

Some controllers use erasable programmable read only memories (eproms). A programmer is needed to an eprom, and, once loaded, it become a read-only device and requires no battery to retain data when the power is removed. The only way to erase the old program is to expose the device to a powerful source of ultra violet light.

EEPROMS, or electrically erasable programmable read only memories, are becoming more popular and function very much like an eprom except that they are erased electrically.

Input and output interfaces

As the input signals can vary from low power dc to high voltage ac, these signals need to be conditioned and isolated from the internal electronics of the controller.

Isolation excludes noise, and conditioning converts the signals to a level the controller can safely handle. Most use optical isolation, which converts the electrical signal to light and optically couples them.

Conversely, the internal output signals need to be changed to a level high enough to drive external field devices. This is achieved by using transistors for dc, triacs for ac, and relays for volt-free applications.

The concept of input and output Sink and Source causes a great deal of confusion and needs to be well understood. The input/output structure of a Programmable Logic Controller consists of two main types: sink and source. Sink may be thought of as an open collector transistor which, when driven ON, is able to "sink" a voltage applied to it, so that any load connected between the output and a suitable voltage would energise when the output was turned on.

This also applies to inputs. Typically the electrical signal is conditioned and filtered, and then passes through a photo diode to sink the input and provide an ON indication to the controller.

Source may be considered as an open emitter transistor which, when driven ON, would "source" a voltage to the load connected to it, so that a load connected between the output and ground would energise when the output turned on.

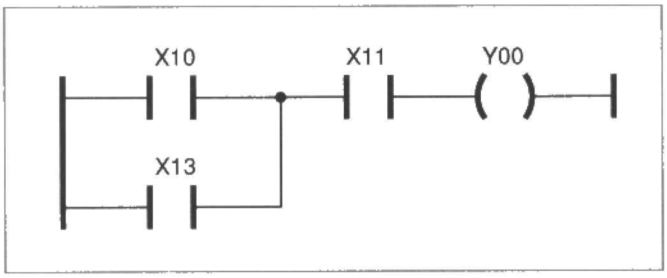
Other forms of output switching are relays and triac devices. Relays depend on mechanical switching for operation and isolation, while the triac is an ac device, capable of switching on both sides of the ac waveform.

Ladder diagram programming

A ladder diagram consists of one line running down the left hand edge with lines branching off to the right. A line branching off to the right is called the Instruction Rung.

Along this rung are placed logical conditions in the form of relay contacts that lead to other conditions. The logical combination of these contacts determines the state of the output coil on the extreme right hand side. See **figure 4**.

Figure 4: a typical ladder rung



Rungs can branch apart and rejoin. Vertical lines are called OR branches (X10 or X13); these combine with horizontal AND lines containing further conditions (X10 or X13 and X11, and so on)

The characters above the condition indicate its type: whether it is the input, the contact of a coil, and so on, and also the address assigned to it. The state of the contact (open or closed) determines the execution condition of following contacts.

The creation of an executable ladder diagram control scheme is basically a three-stage process: (1) draw the ladder diagram (2) compile it (3) download the software to the programmable controller.

A PC is used to develop the ladder diagram, using an intuitive user-friendly graphical environment which provides pull-down menus and dialogue boxes. Within this environment a graphic window is opened allowing the ladder diagram to be drawn using familiar ladder elements such as contacts, coils, etc., which are selected and displayed at the bottom of the screen.

When this process is completed, the ladder diagram is compiled and downloaded to the programmable controller. The relay ladder logic will now be executed when the programmable controller is put into RUN.

Basic procedures

There are a number of steps involved in creating an executable ladder logic scheme using the pc based editing tools. Obtain a list of all the input/output devices and assign an I/O address to each device. Select EDIT from the ladder editor main menu to open a new project file. Then, using the function keys to select the relevant logic symbol, draw the ladder on the screen.

For example, to monitor the state of an input in the form of a limit switch, and to drive a relay output: First assign an I/O address, for example, X10 for the limit switch and Y00 for the relay. Using the function keys, select a normally open contact and address it as 10, then select a coil and address it 00.

You have just created a ladder rung consisting of one contact driving a coil, so that the relay will energise when the limit switch operates. When the ladder diagram is complete, exit the graphics window using F10.

This saves the ladder diagram and returns to the main user screen. Finally, select COMPILE from the ladder editor main menu. Once the ladder diagram is compiled, it can be down loaded to the microcontroller.

Make sure that the programming cable is connected between the PC serial port and controller, and then power up. Selecting PROGRAM DEVICE from the ladder editor main menu now completes the process.

Timers and counters

Up till now we have only considered output coils as the link between the program and the physical device attached to the controller. We now develop the idea of special function coils in the form of timers and counters.

The symbol for both is very similar to that of an ordinary output coil, however, each device has a K constant associated with it. In the case of a timer this value would be the pre-set delay duration before the timer will operate. In the case of the counter it would be the number of OFF to ON signal transitions before the counter output coil would energise.

Before we discuss the operation of both the timer and counter and introduce additional elements necessary to control the devices output coil operation, it is important to understand how the Programmable Logic Controller handles timer and counter data.

Most assign two data registers to the devices, one to hold the fixed K value, the other to hold the actual count or time. This is the actual value that is manipulated. On reset this location is simply loaded with the original K value, and when enabled the data register contents decrement (or increment if an it is an UP counter) on the OFF to ON signal transitions of the counter input.

Commercial Programmable Logic Controllers provide a number of ranges for both timers and counters, normally as follows:

Timer

1 msec 0.001 sec
10 msec 0.01 sec
100 msec 0.1 sec

Counter

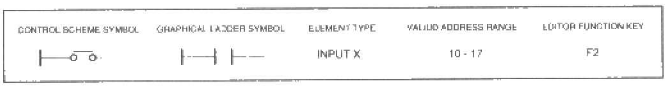
8-bit byte 0 - 255 counts
16-bit integer word
32-bit double word

Integer words allow a maximum of only 32,767 because bit 16 is used to supply the sign when equal to 1 indicates a negative number in the range -1 to -32767.

Ladder diagram instructions

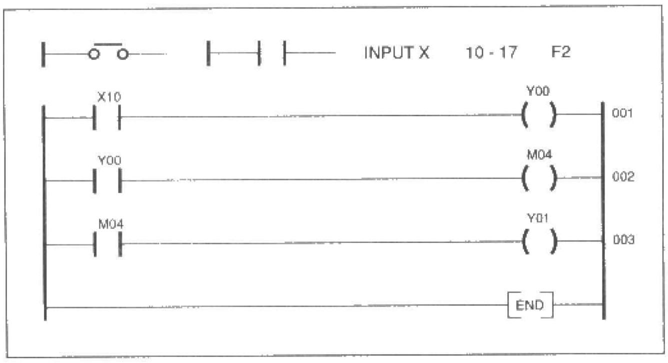
Throughout the next section new instructions will be presented in a consistent form of title line, example ladder diagram and finally an explanation of the ladder presented. **Figure 5** shows a sample title line for a normally open contact.

Figure 5: an example title line.



Normally open contact

Figure 6: Normally open contact

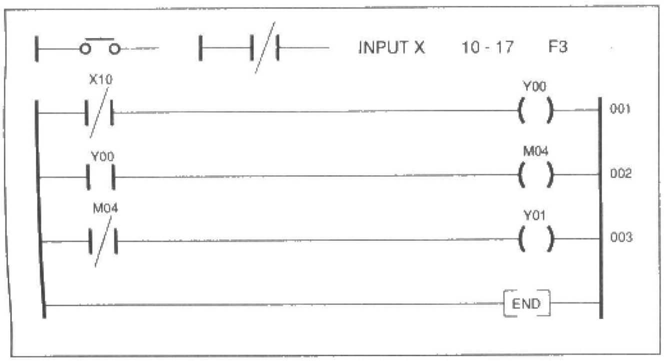


When the controller simulates a ladder relay circuit, what it does is to read any external inputs as already described, then it executes each "rung" in turn, with the results from earlier rungs being available as inputs to later ones.

A normally open contact is ON if the device assigned to its address is operated and OFF if the device is released. When input X10 is energised, output coil Y00 is turned ON, and the normally open contact of Y00 in turn operates internal relay M04. The contact of M04 then operates the coil of Y01.

Normally closed contact

Figure 7: Normally closed contact

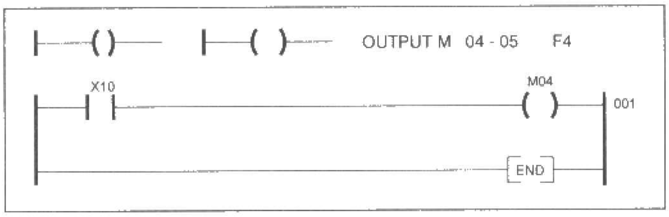


A normally closed contact is ON if the device assigned to its address is released, OFF if the device is operated.

In the initial state with input contact X10 off, output coil Y00 is on and Y01 is off. Normally open contact Y00 operates turning internal relay M04 on, while normally closed contact M04 now operates, turning the output coil Y01 off. When X10 is operated the output coil Y00 is turned off, contact Y00 is released, in turn releasing auxiliary coil M04, the normally closed contact of M04 now operates and turns Y01 on.

Output coil

Figure 8: Output coil

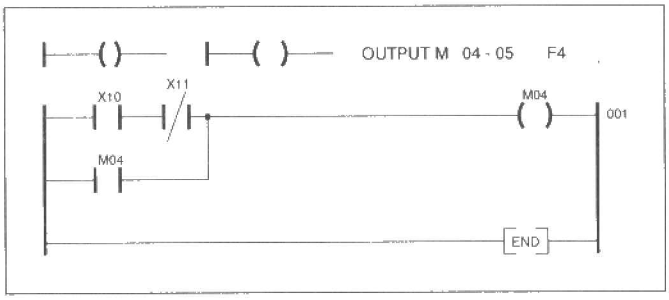


Coils are the program output instructions that link the logical ladder diagram in the form of software and the physical devices connected to the controller and referenced by its address.

In this example, when input contact X10 is made, output coil Y00 will energise and operate the device connected to that address on the output interface.

Internal relay

Figure 9: Internal relay

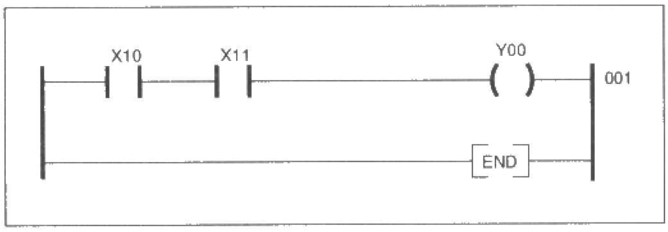


Internal relay coils only exist within the programmable controller, and are used when additional logic is required, eliminating the expense of additional hardwired devices. In the above example, when input contact X10 is made and provided X11 is not operated, coil M04 will energise and operate. The coil will now hold on via its own normally open contact M04 closing, and will remain energised until normally closed contact X11 operates.

This is a typical use of an internal relay as a simple latch.

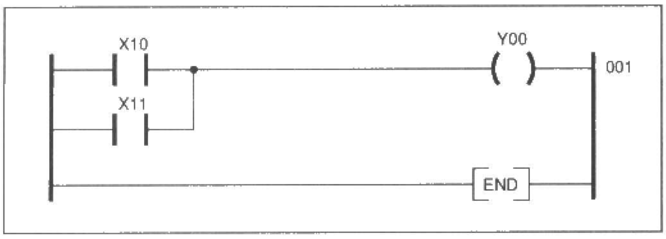
And

Figure 10: And



An AND program instruction may be considered as two or more series contacts. In the above example, if both normally open contacts X10 and X11 were made, then the output coil Y00 would turn on. If either contact is OFF then the output coil would also be off.

Figure 11: Or



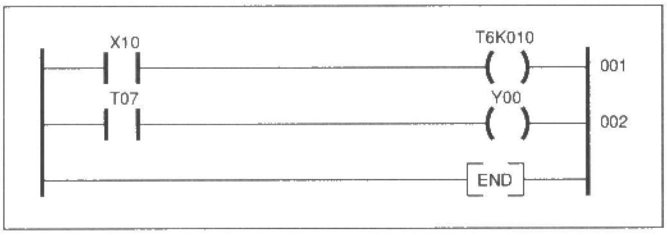
The OR program instruction is just one or more contacts in parallel. In the above example, if either of the normally open input contact X10 or X11 were made, then output coil Y00 would energise. If an OR branch evaluates false, then the reset of the ladder to the right of the OR branch for that rung would also be false.

Timer

As mentioned earlier, the timer is represented as a special function coil with an additional element, a reset enable rung. This is the row of conditions to the left of the coil. If they evaluate true, the timer is enabled but the coil does not immediately operate, as would be the case with an ordinary output coil.

What now happens is that the pre-set constant K value will decrement once every 0.1, 0.01, and 0.001 seconds depending on the time base being used (which is nearly always determined by the timer address). When the K value reaches zero, the timer output coil energises and remains on until the reset/enable rung evaluates false.

Figure 12: Use of the Timer element



If X10 is open, the timer is disabled and the pre-set K value loaded into the actual value register. X10 now operating allows the timer to decrement the actual value until zero is reached. The output coil now energises and remains on until the reset/enable rung evaluates false.

Counter

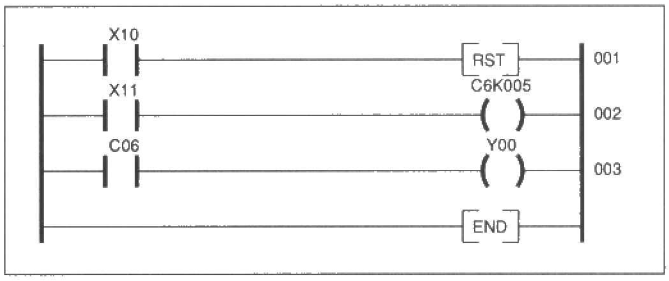
The counter does not have a reset/enable rung as such, instead it uses a special program instruction called RST. If the conditions to the left of its graphic program symbol (usually a rectangle) evaluate true, then the counter is RESET to its original K value.

The actual count rung is the conditions to the left of its output coil and at OFF/ON transitions, up counters would increment from zero up to the K value or for down counters, would decrement down from the original K value to zero.

If the condition to the left of the coil were true, this would enable the count. Therefore, a means of preventing the counter from counting on each scan of the ladder is needed. Counters are only allowed to count on detecting an edge transition, that is, going from logic 0 to logic 1, and a ladder scan could spuriously register as such a transition.

These timer types, on reaching either zero or the K value according to whether the timer uses a down counter or an up counter, the counters output coil would energise and stay energised until the reset instruction evaluated true.

Figure 13: Use of the Counter element. Rung 1 is the reset rung, rung 2 is the timer one, with the timer "coil" designated C6.



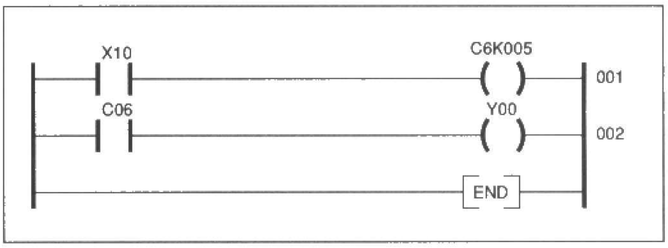
In the above example, input contact X10 made resets the counter, turning its output coil off and reloading the K value into the actual value register. As long as X10 remains madethe counter will not be able to count.

X10 turning off allows OFF/ON pulses on X11 to increment or decrement the counter actual value. When the count value 5 reaches zero the counter output coil energises.

Counter: a special note

The software supplied treats the counter in a different way to conventional programmable controllers, in that it may also be used as a timer and does not have a reset rung associated with it. Selection of the operating mode is made by defining the source of its OFF/ON pulses. For a timer, 0 selects the internal 100ms time base, 17 selects the counter mode and uses input X17 as the OFF/ON source.

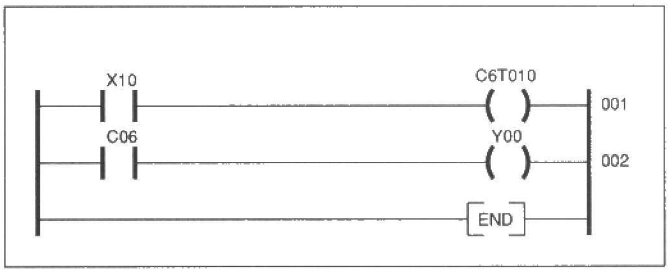
Figure 14: the Counter used as a counter ...



In the example above the count rung now becomes the reset/enable line and the condition of X10 would determine if the counter was enabled, that is, X10 operated counter enabled.

OFF/ON pulses on input X17 would now decrement the counter to zero and operate coil C06, this would stay energised until X10 released.

Figure 15: ... and as a Timer



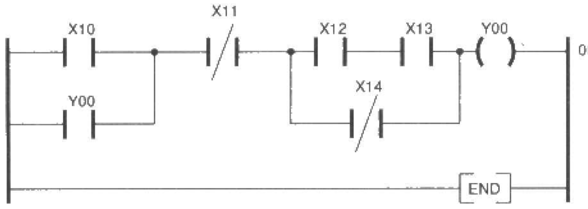
When used as a timer the count rung still becomes the reset/enable line and the condition of X10 would determine if the timer was enabled, that is, X11 operated timer running. The internal 100ms time base would now be the source and, with a K value of ten, would result in a 1 second delay. On reaching zero the timer coil T06 would operate and would stay energised until X10 released.

Introducing Compound Ladder Logic

First I will look at nesting. Complex logic rungs often produce a logic expression that cannot be evaluated without saving the result of previous conditions already evaluated. When this occurs, the result and its logic element need to be saved before the next logical conditions are evaluated. Once these new conditions are evaluated, the previous result and logic element are recovered and combined with the next condition or block of conditions.

As this may be confusing, lets take a look at an example (figure 16) and work through it.

Figure 16: a nesting example



IF THIS LADDER DIAGRAM IS RENDERED AS A BOOLEAN EQUATION, WE GET:

$$Y00 = \overline{X14} + (X12.X13) . (Y00 + X10.\overline{X11})$$

THE LOGICAL ELEMENTS ARE:

AND = +
OR = .
NESTING = ( )
$\overline{Xnn}$ = LOGICAL NOT

Note: The Software made available for use with the project boards that will appear in ETI shortly supports one level of nesting only.

As can be seen from the brackets, there are two occasions when nesting is needed. If we start from the left hand side of the equation, the condition NOT X14 and its logic element OR would need to be saved before the condition (X12 AND X13) was evaluated. After these two conditions are evaluated the previous condition and logic element would now be recovered resulting in (NOT X14 OR binary result), where binary result = X12 AND X13.

This new binary result and the logic element AND would need to be saved while the next block of logic was evaluated Y00 OR (X10 AND NOT X11), which will produce a new binary result.

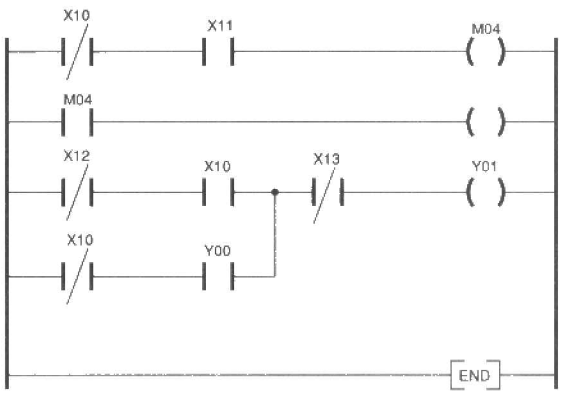
We now recover the previous binary result and the logic element saved with it, and evaluate the logic previous binary result and new binary result. Y00 would now be driven ON or OFF depending on the result of the logic evaluated. The ladder example used would result in one level of nesting, twice in one rung. It would therefore execute correctly.

And again

If normally closed contact X10 was not operated, normally open contact X11 operating would energise internal relay M04, which in turn would operate output coil Y00 (figure 17).

Rung 3 is more complex in that there are now two separate AND paths, NOT X12 AND X10 and NOT X10 AND Y00. If normally closed contact X13 is not operated, either contact X10 or Y00 going true would result in the output coil Y01 operating, provided both normally closed contacts X10 and X11 remain in the released condition.

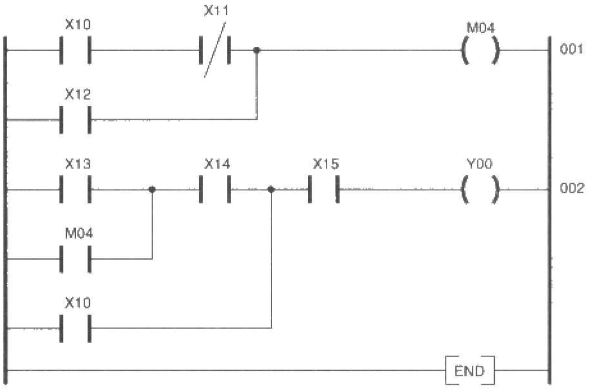
Figure 17: AND again



Or again

As shown below, normally open contact X10 made, and normally closed contact X11 not operated energises auxiliary relay coil M04 (figure 18). There is also another OR path for the operation of M04, normally open contact X10 being made. Again rung 3 is more complex, as we now have multiple OR paths to operate output coil Y00: the first path (X13 OR M 04) AND X14 and the second (X10 AND X15):

Figure 18: OR again



This illustrates that quite complex controls can be implemented easily using a ladder logic representation of the function.

Two example project boards have been designed to go with this article. These appear in this issue of ETI on page 16.

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A microcontroller-based programmable logic controller

This logic controller and interface board provide a practical means of trying some of the principles in the Ladder Logic feature in this issue.

Stephen Fleetham

First an overview. **Figure 1** shows how the hardware components go together. At the heart of the system is the microcontroller PCB, which is where the ladder diagram software is downloaded and executed. To accomplish this we need to use the ladder logic editor/compiler software running on a standard PC.

Now some form of interface between the microcontroller PCB and the external hardware must be provided. For this project a simple 'user hardware' eight-in four-out PCB is used. Connections between the two boards is made using a 16-way ribbon cable, which plugs into the 16-way dil sockets on both pcbs. The ribbon cable is terminated at either end with 16 way IDC connectors.

For those not familiar with the technology, the connector consists of two parts, the main body and a top cover. The main body contains the insulation displacement pins which are forced through the ribbon cable by fitting the top cover and compressing the assembly under pressure. This operation makes the electrical connection.

The microcontroller PCB circuit is reasonably simple and consists of three ics and a small number of discrete components. It is easy to construct either on Vero board or using the PCB.

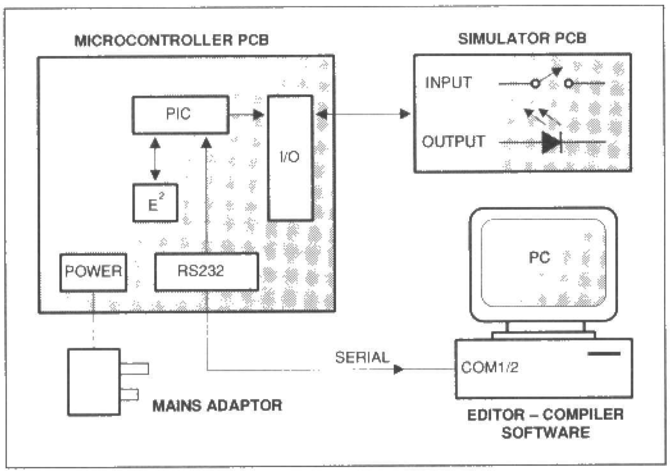


Figure 1: an overview: the microcontroller pcb and simulator pcb connected to a mains adapter and a PC

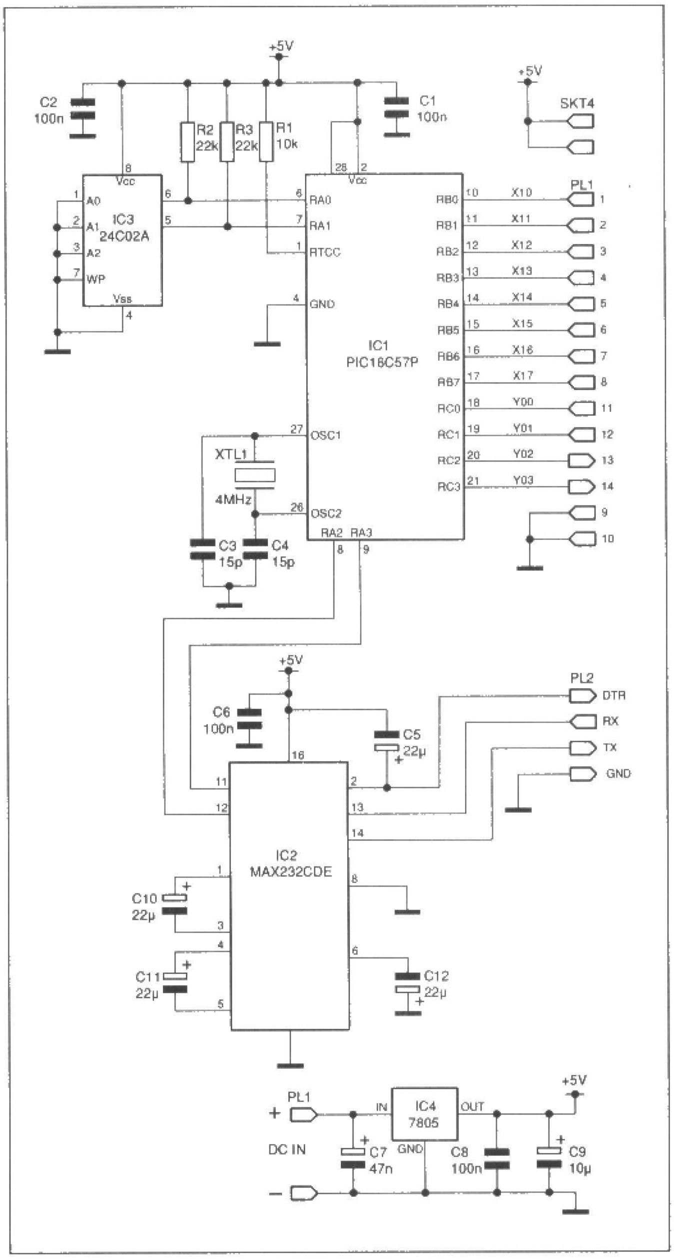


Figure 2: the circuit of the microcontroller board

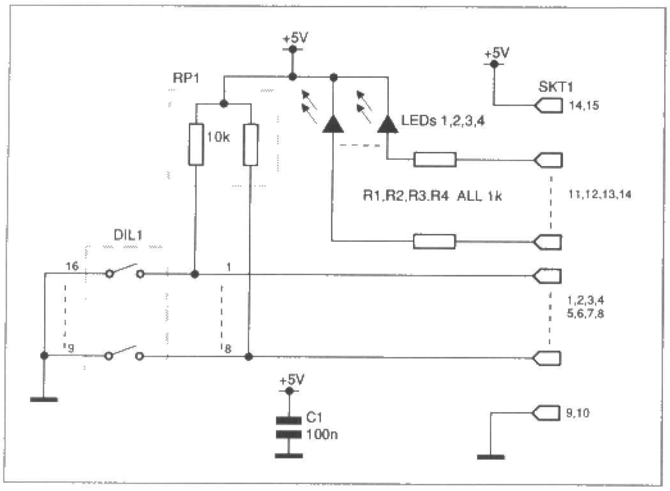


Figure 3: the circuit of the simulator board

If we now refer to **figure 2**, the microcontroller IC1 controls the hardware operation and is supplied pre-programmed with a 'runtime' software package. This software determines the condition of the inputs, then reads in a byte of binary code from eeprom IC3.

Looking at the main ic first, IC1 is a PIC microcontroller which is a programmable device here configured to provide the input/output and serial communication ports. Thisalso generates the necessary timing and clock signals to program the on-board memory device IC3. The on-chip one time programmable memory contains a runtime software package.

This software controls the operation of the pcb by reading the input ports evaluating the eeprom stored binary logic and driving the outputs as necessary. The logic instructions along with input and output address are embedded in this binary byte.

Serial communications is also provided by IC1, which takes the internal data and generates, through software, the timing necessary to send and receive start/stop and data bits to and from IC2. This software implements an on board UART, saving the cost of an additional external component.

As the pcb provides a RS232 serial port a means of changing the +5V TTL level signals to the positive and negative voltages defined by the RS232 specification is needed. This is provided by IC2, which contains a charge pump circuit. This, with the use of a small number of external capacitors can generate +/- 10VDC and convert between RS232 and TTL voltage levels.

This only leaves the operation of IC3 to be explained. This is an electrically erasable programmable read only memory. Eeproms are programmed serially as opposed to conventional memory which is either byte or word parallel format. Some means of synchronising this serial transfer is required. IC1 provides this timing by generating a clock signal on pin RA0, allowing the hit data on RAI to be transferred to IC3.

The LED on the microcontroller pcb gives an indication of the current state of operation. If it remains on or off it indicates microcontroller execution halted; if it is pulsing then the system is running.

Finally, IC4 regulates the input voltage down to the 5V DC for the operation of the hardware, by converting an unregulated input supply in the range of +8 to 15VDC down to +5VDC. Its input voltage should not fall below 8V during the lowest point of the ripple (if an unregulated supply is used) at the maximum load. If a voltage above around 10V is used, it would be advisable to use a heatsink on the regulator.

If the power supply is towards the higher limit specified above, the heatsink on the voltage regulator, IC4, may need to be quite substantial.

Microcontroller pcb construction

To enable a single sided pcb to be produced there are a number of wi re links to be fitted, using scrap component leads. It is best to fit and solder these first.

Next fit and solder all resistors before the other components are inserted. The ic sockets and PL2 are next, note the orientation of the pins, pin 1 of each socket is towards the top of the board. Insert and solder the remaining capacitors and IC4. Care must be taken to ensure the voltage regulator IC4 is inserted correctly; the metal tab for an optional heatsink must be to the right when looking down from the top.

Now visually inspect the pcb for dry joints or short circuits, which are the most common causes for a circuit to fail to operate correctly. Also, check that all component. leads and wire links are soldered.

With IC1, IC2, and IC3 removed, connect the external power source (between +9 to +24VDC at around 250mA) and check with a meter the voltage regulator is delivering +5VDC +/- 10 percent. If excessive current is drawn from the 5V supply, a heatsink may be attached to the metal tab on IC4.

Finally fit IC1, IC2, and IC3 and ensure that pin 1 of the IC matches pin 1 of the socket installed. The power supply to the pcb should be greater than 8VDC and less than 15VDC at around 250mA.

To program, power up the pcb and attach a 9-pin serial lead to the PC. Run the Editor/Compiler software (com1 is the default communication port. Use the command line argument /com2 to select com2) and using the menu, select the operation required.

Simulator pcb construction

If we now look at **figure 3 & 4**, the second small I/O pcb is very simple, and consists of an 8- way dil switch DIL1 simulating eight digital inputs, and LEDs 1,2,3,4 providing four simulated digital outputs.

The construction of the PCB is easy. Fit and solder all the components making sure RP1 and SK1 pin 1 are in the correct location as indicated on the layout, and take care to ensure the LEDs are fitted correctly with the flat side going to R1,2,3,4.

The simulated inputs and outputs are connected to the microcontroller pcb by the 16-way IDC ribbon cable assembly mentioned earlier

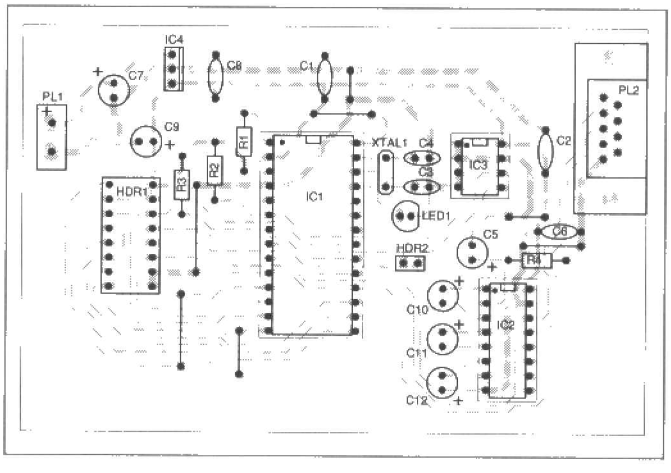


Figure 4: the component layout of the microcontroller pcb

PARTS LIST for the Microcontroller Board

Resistors

R1	10K 0.25 watt resistor
R2	22K 0.25 watt resistor
R3	22K 0.25 watt resistor
R4	3K0 0.25 watt resistor

Capacitors

C1,2,6,8	100nf ceramic disk
C3,4	15pf ceramic disk
C5,10,11,12	22uf 40V electrolytic
C7	47uf 35V electrolytic
C9	10uf 10V electrolytic

Semiconductors

IC1	PIC 16C57P Microcontroller - see below
IC2	MAX232CPE TTL to RS 232 conversion
IC3	24C02A EEPROM relay ladder logic data
IC4	7805 voltage regulator
XTL1	4MHZ Ceramic resonator
LED1	general purpose LED

Miscellaneous

PL1	2 way power
PL2	9 pin D type female
SKT1	40 pin DIL socket
SKT2	16 pin DIL socket
SKT3	8 pin DIL socket
SKT4	16 pin DIL socket
PCB1	optional printed circuit board
HDR2	2-pin header
Heatsink for IC4	

A REAL WORLD APPLICATION: A MOTOR CONTROLLED ROLLER BLIND

This example of real-world programming discussed may be programmed into the microcontroller board, and using the project PCBs the ladder logic software may be run and monitored using the software package mentioned previously.

The purpose of this example is to show how ladder diagram programming and microcontrollers can replace conventional hardwired control schemes. The design of associated hardware is not covered, and is left as an exercise for the reader, however, the input - output simulator may be used to allow the ladder diagram to be run and the resulting operation monitored. **Figure 5** shows an example of the power wiring needed to control a conventional heavy-duty motor driven roller blind.

PARTS LIST for the Input/Output Simulator Board

All components

RP1	4k7 8-way resistor pull up
R1,2,3,4	1k 0.25 watt resistors
C1	100nf ceramic disk
LED 1,2,3,4	
SKT1	16 pin dil socket
DIL1	8 way direct in line switch
PCB1	printed circuit board (optional)
Cable assembly	6way IDC ribbon cable

IC1 contains a 'runtime' software package and also a software key to allow the supplied Ladder Editor/Compiler to run in full development mode. The ladder logic compiler/editor software and the self teaching/user manual, on which these articles are based are also available from Micro Technical Services (see the end of this article).

An example of a hard wired relay control scheme to control the operation of the roller blind is given in **figure 6**, the operation of which is quite straightforward.

The next thing to be done is to put together the control scheme. First draw up an input output schedule which specifies the electrical nature of each input output as in **table 1**.

Input	**Description**	**Tag**
X11	Up push button	PB1
X12	Down push button	PB2
X13	Emergency stop	ES1
X14	Upper limit switch	ULSW
X15	Lower limit switch	LLSW
X16	Motor over current	OL
X17	Safety switch	SFW

Output	**Description**	**Tag**
Y00	Up relay	RL1
Y01	Down relay	RL2

Table 1: the I/O schedule

The hard wired relay control scheme is then translated to its ladder diagram equivalent, **figure 8**. Obviously the two are very similar, however, on this diagram certain devices only exist within the Programmable Logic Controller, such as auxiliary relay M04.

This is the software that links the logical internal elements, the contacts coils etc., to the real world physical devices, the relays, limit switch etc. It also provides the sequential control and operation of the external components based upon the condition of the inputs of the Programmable Logic Controller.

The actual wiring diagram is now drawn up **figure 9**. Notice the simplicity of the layout when compared to the hard wired relay control scheme. Any mistakes in the logical operation of the roller blind can now be quickly rectified by altering the ladder diagram, and reprogramming the Programmable Logic Controller. This is significantly easier and cheaper than having to rewire a conventional hard wired relay panel.

Hardwired circuit description

On pressing the up push button PB1 control relay RL1 operates and normally open auxiliary contact of RL1 operating holds the control relay in. The push button may now be released.

At the same time the three-phase contacts make apply mains to the motor which now starts to raise the roller blind. The motor continues to operate until the normally closed upper limit switch ULSW operates. This releases relay RL1 and the motor is stopped.

To lower the roller blind the down push button PB2 is operated, RL2 energises and normally open auxiliary contact of RL2 operating holds the control relay in, the push button may now be released. This drives the roller blind down until its closed position is reached, which is detected by the normally closed lower limit switch LLSW.

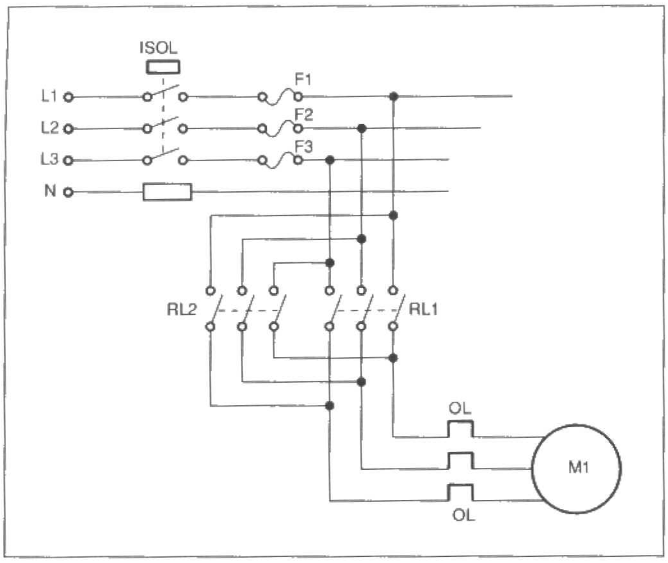


Figure 5: an example of the power wiring needed to control a conventional motor-driven roller blind

To provide a measure of safety, the motor is protected from over current by overload OL. An emergency stop switch ES1 is provided as a means to release both up and down relays, stopping any roller blind movement.

As an added precaution a 'bump strip' SFW is fitted to detect any contact with an object while the roller blind is being lowered. Any contact detected would stop the roller blind by releasing the down relay RL2 removing the drive to the motor.

Ladder diagram circuit description

Master current overload normally closed contact X16 operates internal relay M04, this acts as a safety circuit to release output coils Y00 and Y01 should X16 operate due to overcurrent.

Rung 2 provides the door up logic as normally open contact X11 operating energises output coil Y00, this causes output coil Y00 to latch on via its own normally open contact Y00. Normally closed contact Y00 ensures that the down coil Y01 is not able to be driven while the door is opening.

The door will now open until the normally closed contact X14 upper limit switch operates. This releases Y00, removing power to the motor via RL1 contactor.

The down control is taken care of by Rung 3, operation is similar to the up control already discussed, however, for safety sake a 'bump strip' is attached to the leading edge of the door. This operates normally closed contact X17 in the event of the door making contact with an object while being shut, which releases Y01 which in turn removes the power via contactor RL2.

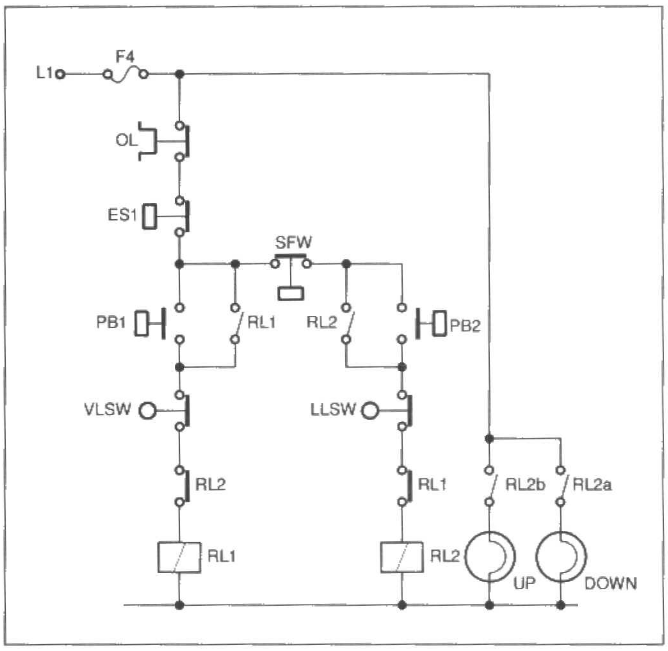


Figure 6: a example of a straightforward hard-wired relay control scheme

An example of the ladder diagram needed to control the roller blind was given in figure 8.

An important note

In practice, the emergency stop button should ALWAYS be hardwired to allow physical disconnection of the mains power to the control relays, and normally the switch will be mechanically latched off until reset.

I hope that these practical examples and the previous feature on the subject have helped to open the door to Programmable Logic Control and ladder logic.

Hardware and Software

The following items are available to accompany this article:

IC1 and IC3 (IC3 is initialised with a default ladder run so that there is no need for the bootstrap loader): £14.99 plus £2.75 post and packing.

Software £14.99 plus £2.50 post and packing.

Orders and enquiries to: Micro Technical Services, Unit 13, Graham Potter Enterprise Units, Pinehurst, Swindon, Wilts, SN2 1RL.

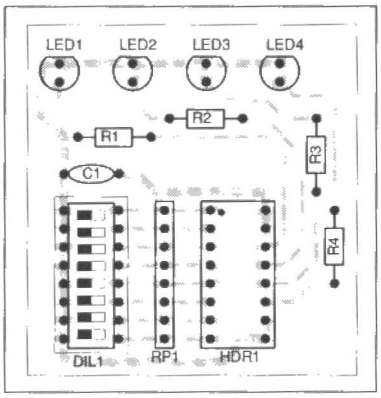


Figure 7: the component layout of the simulator pcb

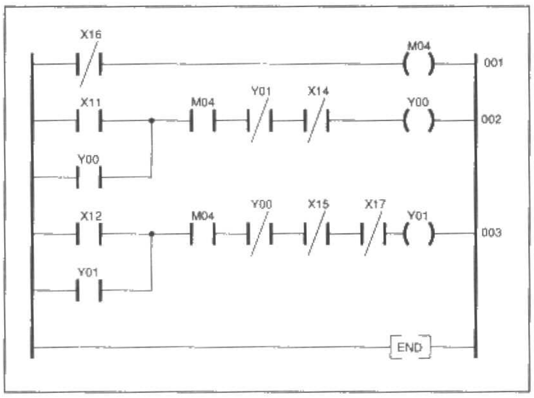


Figure 8: the hard-wire control scheme of figure 6 translated into an equivalent ladder diagram

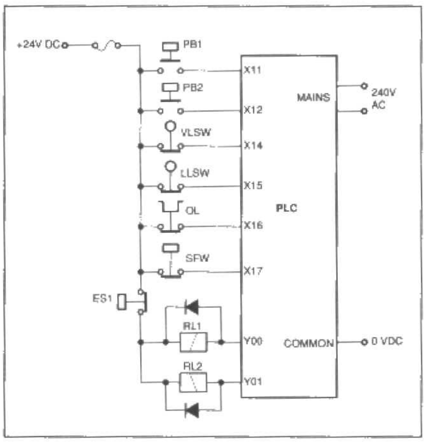


Figure 9: the actual wiring diagram generated from the ladder diagram in figure 8

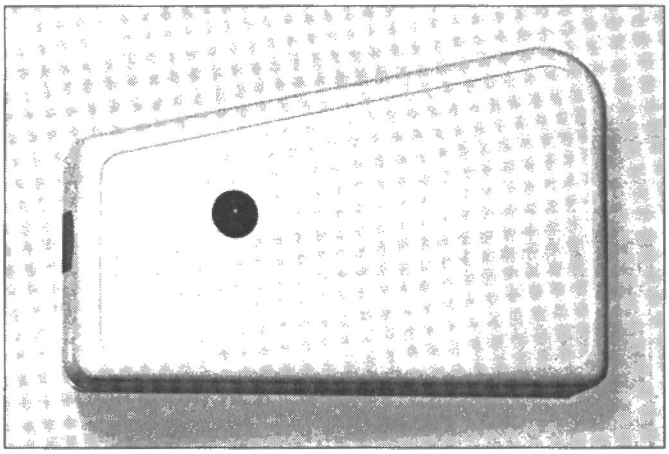
Christmas Lights Tester

This neat little Christmas Box helps to track down those elusive "off" lights by detecting an electric field. It can also be used for continuity-testing small components.

Bart Trepak

Christmas comes but once a year and when it does ... as well as bringing good cheer it also brings the usual crop of seasonal questions. Will the mother in law be coming to stay again this year? ... what will Santa bring me? ... is it worth putting a fiver on a white Christmas? ... *will the Christmas lights light?* ... Being an electronics designer, I am unable to give a solution to many of these problems but this article should help to fix the last one should it occur - and experience shows that it usually does.

Murphy's law - the one that states that if anything can go wrong then it will - operates all the year round. With a 40-lamp set of Christmas tree lights, there are at least 40 things to go wrong (41 if we count the mains fuse), so it's a fairly safe bet that they will not work first time when they are brought out of hibernation. As the lamps are connected in series, any one lamp failing or not making a good contact with its connector will result in the whole chain failing to light. Many newer lamp sets are fitted with special lamps which go short circuit when they fail so that even when one lamp fails, the circuit is maintained and only that lamp fails to light. This makes it easy to spot and replace the offending lamp. If more than a few lamps fail in this mode, however∏ and go unnoticed (as can easily happen with small bulbs on a large tree), a greater stress is placed on the remaining lamps as the current through the chain increases. This may eventually cause the fuse (or the fuse lamp) to blow.



Even with these lamps fitted and the fuse intact, it is still possible for one or two lamps to fail to make proper contact with their connectors. Even one faulty contact, irrespective of the condition of the lamps, will cause the chain to fail. Most lamp sets have a rather crude arrangement for connecting lamps to their holders, relying on a tight push fit and a specially shaped plastic lamp base which causes the two bare lamp wires to come into contact with two small brass or copper plates within the holder. Having been stored for a year in what are probably not ideal conditions, the lamps can easily work loose or the contacts oxidise resulting in the set failing the following

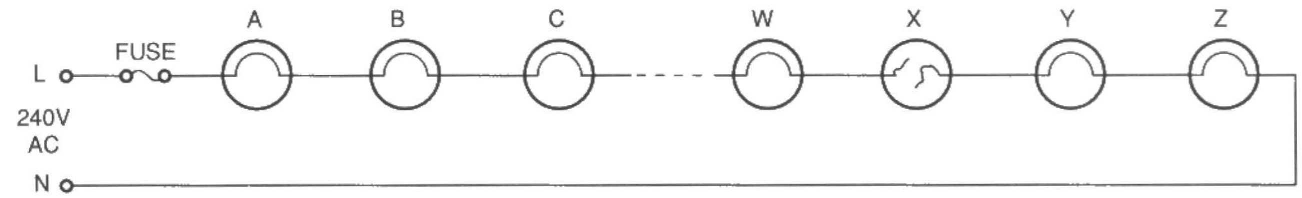


Figure 1: a Christmas tree lamp chain, showing a break at X

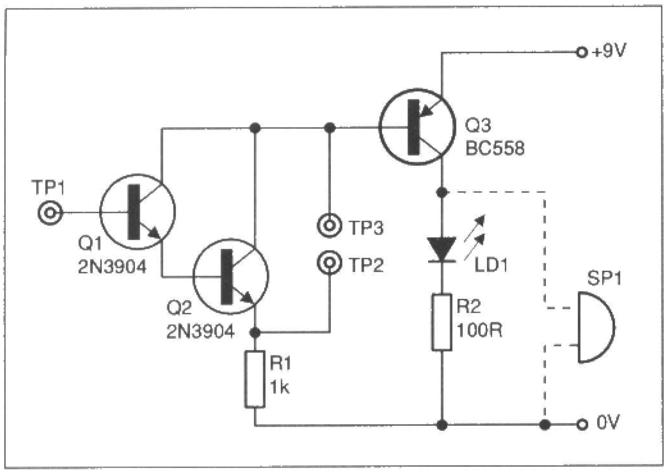


Figure 2: the circuit of the Christmas lamp tester

year. You are then left scratching your head to try to decide on the quickest way to pinpoint the trouble.

The normal procedure adopted is to start at one end of the chain, remove each lamp in turn and re-seat it in its holder, testing the whole chain each time to see if this has cured the fault. With the older lamps, each lamp will also need to be tested to ensure that it has not gone open circuit. Typically, the fault will be located in one of the last lamps in the chain. Add to this a failure when the set is already on the tree, with sharp pine needles sticking into your fingers each time a new lamp is removed or fitted, the children anxious to get on with decorating the tree and the dog sniffing around the base. This is something you can do without, isn't it?

The answer, of course, must be to pick one end of the chain and then quickly nip round and start at the other end ... in which case the fault will be found in one of the first lamps to be tested. If it were only that simple!

The best present from Santa?

Surprisingly, the electronic answer is nearly that simple, as the following circuit shows. It will enable the problem to be pinpointed quickly and easily without the need to disconnect all the bulbs or any of the other aggravation. Not only that, but the unit will probably be found very useful during the rest of the year for a variety of tests on fuses, lamps, mains cables and so on.

Any conductor such as a chain of Christmas lamps connected to the mains will have an electric field associated with it. This is true even if no current is flowing in the conductor, and it will also be the case if there is a break in the chain. This circuit is designed to detect this. Figure 1 shows a set of lights connected to the mains with a break in the circuit at point X due to the lamp being blown or not fitted correctly. Beginning at the live terminal therefore, the field will exist at points A, B, C, etc. all the way along the conductor until point X is reached. At this point, there will be no field and the circuit will indicate this problem area. All you have to do then is test the lamp, clean the contacts or simply push the lamp firmly into its holder. If more than one lamp or connector is faulty, the first one in the chain will show up. When this has been rectified, subsequent ones can be found.

There is a small problem with this arrangement, and this is due to the fact that most lamp sets, if not all, are wired exactly as shown in **figure 1** and not with the lamps spaced equally along whole the length of the conductor. The long neutral tail is then twisted around the other conductor, so that it is impossible to test one wire without the other being present. As long as the chain is connected to the mains as shown, with the lamps nearer the live end there will be no problem, as it is the Live wire which is responsible for the electric field.

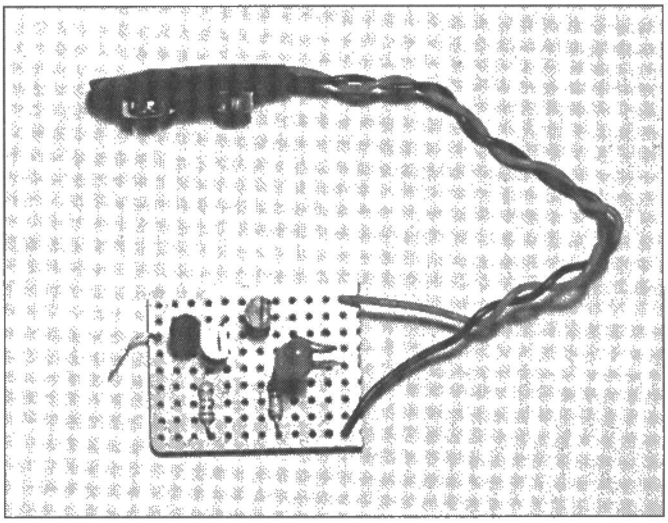
The neutral wire is of course at (nearly) earth potential and so the field due to this is at most very small - the tester should then respond only to the field due to the Live wire and the absence of this field can therefore be easily detected. Assuming that the chances of a break in the actual neutral wire are small (and indeed, if this were the case, the chain would probably not be worth repairing), any faults will therefore lie either with the lamps themselves or with their holders. With a break at X, all the wires to the left of this point will show a field while those to the right will not, as they will be at neutral potential.

If the chain is connected to the supply the other way around, however, with the terminal marked L on the diagram going to N and N to L, there would be an electric field along the whole length of the chain irrespective of a break, because the conductor connected to L would run along the whole length of the chain. Of course, on Christmas lights both conductors are usually coloured green, so that it is impossible, without unravelling them, to tell which is which. Should the chain fail to work, but a field is nevertheless detected along the whole length of the cable, the connections to the chain should be swapped either by reversing the plug in the case of a 2-pin mains connector, or by re-wiring the mains plug.

Detecting electric fields

An electric field can be detected simply by placing a conducting probe (that is, a piece of wire or a plate) within it. Once in the field, the probe will assume the potential of the field at that point. With an alternating voltage, the field will of course also be alternating. The problem is to produce a meaningful display from this. Connecting a normal voltmeter to the probe and earth will not usually show a reading because this will load it too much. What is needed is a high input impedance buffer or amplifier if we want to drive some sort of indicator.

This circuit consists of a very high gain amplifier with a high input impedance consisting of only three transistors, two resistors and an LED, as the diagram of **figure 2** shows. The first two transistors are connected as a Darlington, giving a combined current gain equal to the



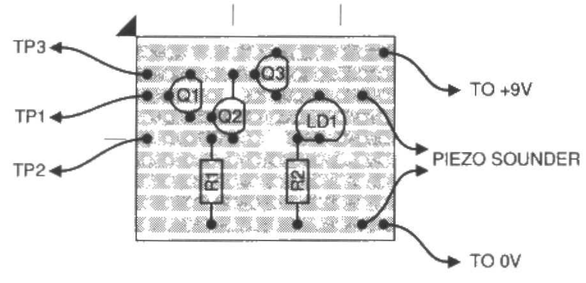


Figure 3: the component layout on Veroboard

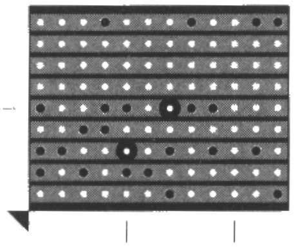


Figure 3a: the back of the above layout, showing track cuts

product of their individual gains. With the devices specified, this should be around 10,000. The input impedance will be around 10 megohms.

The current from this is fed directly to the base of a PNP transistor which drives the LED. An optional piezo sounder can also be connected if an audio indication of the field is required.

The circuit will operate on any voltage down to around 3 volts, so that any battery from a 9-volt PP3 to two 1.5-volt AAA cells can be used although, at the lower voltages, the sound obtained from the piezo will not be so loud. The current consumption of the circuit, even when it is operating, is so small that no on/off switch is required and batteries should last for virtually their shelf life.

Construction and uses

The circuit is small enough that the unit could be conveniently constructed on a piece of strip-board. A suitable layout for this is shown in **figure 3** but the layout is not critical and can easily be altered. Most of the components will probably be to hand, but they are all of easily obtainable kinds. Almost any other high gain NPN and PNP transistors may be used (note that the pin-outs may vary) and Darlington transistors such as the BC517 could also be used in place of the two NPN devices. Note the pin-outs of the 2N3904 (**figure 4**), which differ slightly from many other small signal transistors. This should be borne in mind if other types are used instead.

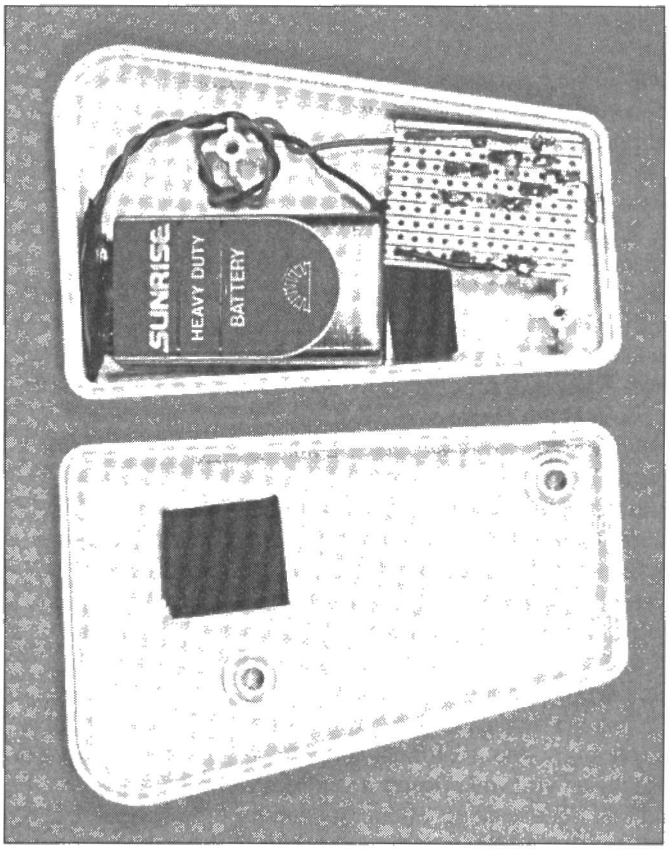
The sensor TP1 I orginally breadboarded consisted of a drawing pin connected to the base of the first transistor by a short wire. The one on the cased unit (see photograph) is simply a strip of strong copper foil folded over the edge of the lower part of the case. (We had one of those component supply problems here: the technician couldn't find a drawing pin.) The sensor is mounted on the outside of a plastic box at a convenient point together with the circuit which may be secured to the box by means of the LED clip as there are no heavy components to be supported. The size and internal layout of the box is left to the constructor as this will depend to a large extent on the type of box available, the battery used and whether a piezo sounder is fitted or not.

If the two other sensors TP2 and TP3 (not on the prototype) are also fitted to enable continuity tests to be made, these should be connected on opposite sides of the box so that they will not be accidentally shorted out if the unit is stored in a metal tool box.

Once construction is complete, the circuit may be tested by bringing the sensor close to a cable connected to the mains. The LED should light when the sensor is within 3 or 4 mm of the live conductor. If the sounder is fitted, this will give a 50Hz buzz. The circuit does not require any adjustment and any fault should be easy to trace.

The use of this circuit for fault finding Christmas tree lights (or tracing any break in a live conductor) is quite simple and consists of running the sensor along the chain between the lamps until the LED fails to light which will indicate the position of the fault. The tester will also be useful in general electrical work around the house such as testing if a mains cable is live prior to carrying out some work near it. This has a great advantage over using, for instance, a mains tester screwdriver or a voltmeter, which require a direct contact with the conductor, as the insulation does not need to be removed. However, you must REMEMBER TO TEST THE UNIT BEFORE USE especially if any work is to be carried out on a conductor, as the LED could fail to light because the battery is flat or disconnected (for example). It may also not work with cables inside a metal conduit, as these often produce no external field to be detected.

Another function which is often required is testing the mains fuse in a plug fitted to an appliance. Plug the appliance into the mains socket (make sure the mains socket is switched on) and use of the tester will indicate whether the appliance cable is live. If it is not, unplug the



appliance and check whether the mains fuse has blown. Don't dismantle mains leads or appliances, even apparently "non live" ones, until the appliance is switched off and disconnected.

The tester unit should not be used as a cable detector for cables buried in a wall. Although it may indicate the presence of a cable, this is not reliable due to its short range and other effects such as damp in the wall.

Testing component continuity

The versatility of the unit can be increased by providing another pair of contacts (shown as TP2 and TP3 on **figure 3**), which will enable continuity to be tested. Bridging the contacts by touching one pad while holding the box in one hand and touching the other with the other hand will cause the LED to light by providing a base current for Q3. This will allow fuses and lamps to be tested by touching the sensor with one lead while holding the component by the other. With a bit of practice, diodes, LEDs and even capacitors may be tested. Diodes and LEDs will cause the LED to light when connected one way around but not the other while with capacitors, the LED will light briefly as the capacitor charges although with larger values the LED may stay on for several seconds. With electrolytics which have a higher leakage current, the LED may remain on with a reduced brightness while smaller capacitors (less than 100nF) may not light the LED for long enough to be noticed. If the test points are shorted together, the maximum current will be limited by R1 to around 9mA with a 9-volt battery so that semiconductor junctions may be tested safely. LEDs connected directly to the test points will light if connected the right way around (cathode to TP2) so that the polarity of diode components can also be determined.

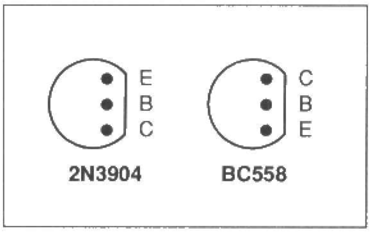


Figure 4: the pin-outs for the 2N3904 and BC558. Other transistors can be used, but note that the 2N3904 has a slightly unusual pin arrangement and adjust accordingly if substituting

PARTS LIST

for the Christmas Lights Tester

Resistors

R1	1k
R2	100R

Semiconductors

Q1,Q2	2N3904 NPN transistor
Q3	BC558 PNP transistor
LD1	Red LED

Miscellaneous

Stripboard (9 strips x 13 holes), battery connector, metal-headed drawing pins, Piezo element (optional); box.

Unlike many Christmas presents which may lie forgotten after a few days or weeks, this one could still be in use the following November and turn out to be the most useful present from Santa - even if you had to make it yourself!

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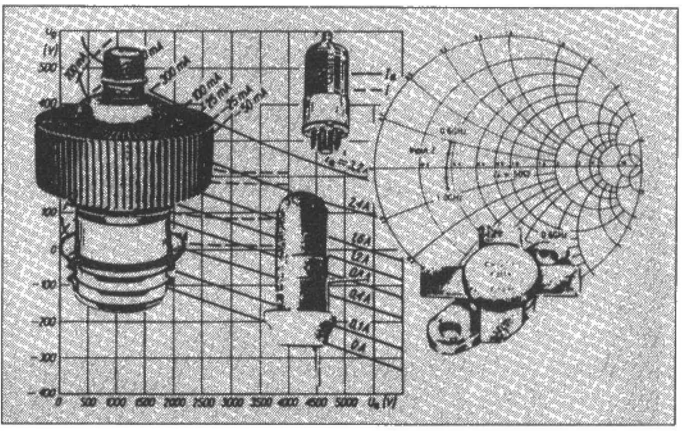

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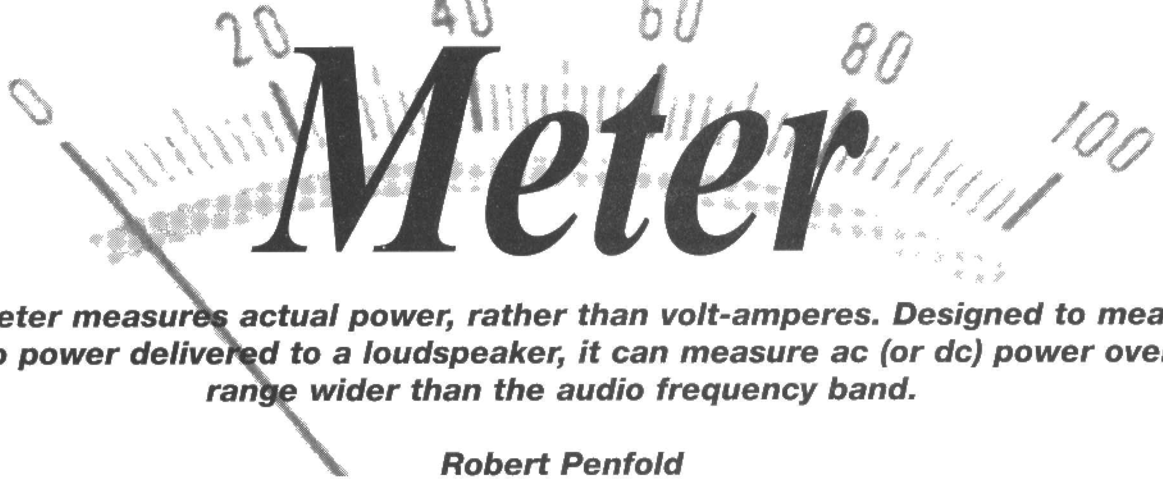
Audio Power Meter



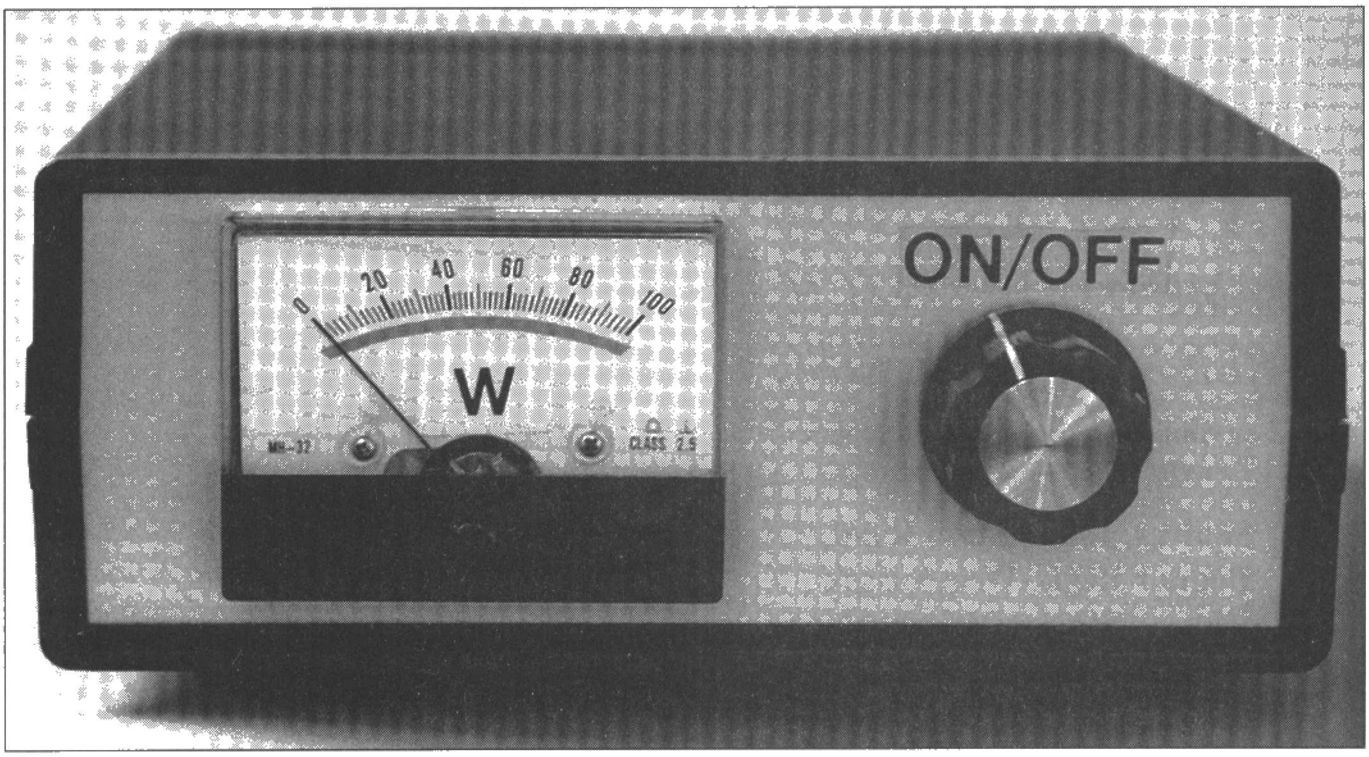
This meter measures actual power, rather than volt-amperes. Designed to measure audio power delivered to a loudspeaker, it can measure ac (or dc) power over a range wider than the audio frequency band.

Robert Penfold

Measuring the output power of an audio amplifier is something that is actually quite easy in principle if you are prepared to do some simple arithmetic and use accurately known load resistances. Power is equal to voltage multiplied by current, so it is basically just a matter of measuring the output voltage from the amplifier, and then using Ohm's Law to calculate the current. Mutiply the output voltage by the output current and you have the output power of the amplifier.

Matters are not quite so straightforward when using an actual loudspeaker rather than a resistor to act as a dummy load. Although a loudspeaker may have a nominal impedance of (say) 8 ohms, it represents a complex load having impedance which varies significantly with changes in frequency. This is partly due to the fact that the coil of a moving coil loudspeaker is inevitably inductive and does not provide pure resistance. It is also due to the mechanical nature of a loudspeaker, complete with its mechanical resonances and all the rest. A loudspeaker does not provide a straightforward load that can be expressed in terms of simple inductance and resistance. You can calculate the output power of an amplifier working on the basis of the loudspeaker genuinely having its marked impedance, but the power rating derived using this method could be well wide of the mark. It is for this reason that power-rating measurements are normally made using a resistive dummy load and not a loudspeaker.

Life would clearly be much easier if audio output power could be measured using a piece of test gear that measured the true output power regardless of whether the load was resistive, capacitive, inductive, or any combination of these. It would also be helpful if it did the calculating for you and provided a direct readout of output



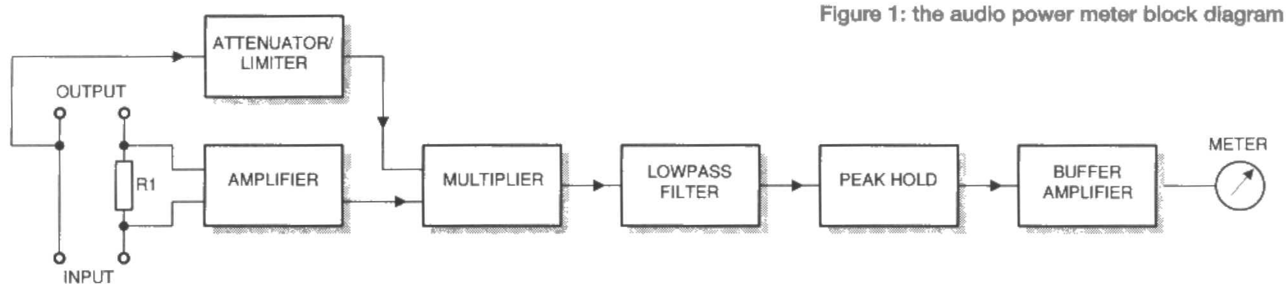


Figure 1: the audio power meter block diagram

power. This is precisely the function of this project, which measures average output power from zero to 100 watts. The reading is provided on a moving coil meter that has a normal forward-reading linear scale. Consequently, there is no need to recalibrate the scale. The unit is powered from a 6-volt battery, which means that none of the inputs of the unit are earthed. It should therefore work perfectly well with amplifiers that have neither output at earth potential, such as bridge types.

The current measuring section of the circuit places 30 milliohms in series with the output of the amplifier. Any additional resistance in series with the load is clearly undesirable, but the power loss through the unit is less than one percent with a four ohm load, and is only 0.375 percent with an 8- ohm load. This is totally insignificant, as is the affect on the damping of the loudspeaker. The unit can therefore used to monitor the output of an amplifier while it is in normal use without producing any significant degradation in performance. In order to calibrate the unit a high-power 4- or 8-ohm dummy load is required, together with a meter capable of measuring AC voltage accurately.

System operation

In order to produce an output power reading, the circuit must measure the output voltage and current multiply the two readings together, and then average the resultant signal to produce a DC output voltage. This voltage is proportional to the average output power of the amplifier. It is possible to obtain the desired effect using digital or analogue techniques, but the design featured here uses purely analogue circuitry. The block diagram of **figure 1** shows the general scheme of things used in this output power meter.

The power meter is added into the two leads, which connect the output of the amplifier to the loudspeaker or dummy load. This enables both voltage and current to be measured. R1 is included in series with one of the leads, and the voltage developed across this resistor is proportional to the current flowing through it. The value of R1 must be very low so that it does not significantly add to the load impedance or significantly impair the damping factor of the amplifier, but this gives only a modest signal voltage even when high output currents are present. An amplifier is therefore used to boost this signal to a level that will drive the multiplier properly. The other input of the multiplier is fed with the output voltage from the amplifier, but at high output powers this signal will exceed the maximum usable input voltage for the multiplier. In fact it could be high enough to damage the multiplier chip. An attenuator reduces the input voltage to a more suitable level for the multiplier, and a limiter circuit ensures the safety of the multiplier chip if a severe overload should occur.

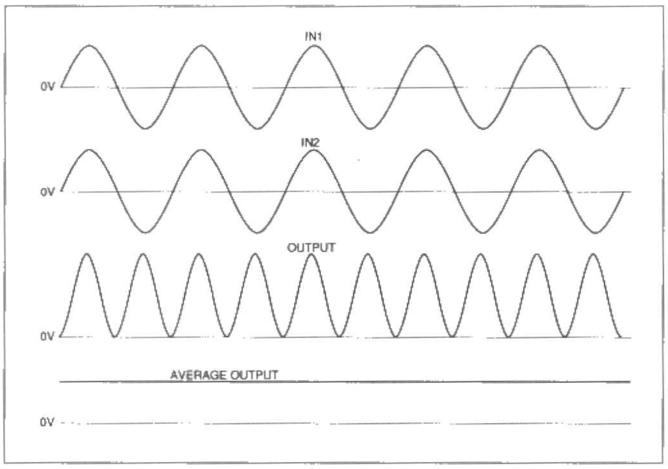


Figure 2: with in-phase input signals the multiplier provides frequency doubling and effectively full-wave rectifies the input signal

Phase relationships

When the load is purely resistive the inputs to the multiplier will be in phase, as in the top waveforms of **figure 2**. Although one might expect the output waveform to be much the same as that of the input signals, this is not the case. The output is actually at double the input frequency. The salient point here is that multiplying two negative quantities produces a positive result. This produces positive peaks on the output signal for both the negative and positive peaks at the input, and a consequent frequency doubling action. Of more importance in the present context, the output signal is always positive. There is no need to provide any rectification prior to smoothing the signal to produce a DC output level. The output of the multiplier can be fed direct to the lowpass filter.

If the load is not purely resistive, but includes capacitive and/or inductive reactance, the voltage and current signals will not be precisely in phase. In an extreme example the two input signals would be 90 degrees out of phase, giving the waveforms of **figure 3**. This still gives a frequency doubled output signal, but we are now multiplying voltages that have mixed polarity for 50 percent of the time. This means that the output signal is negative for 50 percent of the time, and the average output voltage is zero. The circuit therefore registers zero output power. This is correct, because the power supplied to the load on one set of half cycles is being returned on the other, and there is no power dissipation in the load. The output current that flows is so-called "imaginary" current, and not the "real" output current that flows into a resistive load. Whatever combination of resistance, inductance, and capacitance the load provides, this power meter will ignore "imaginary" output current and accurately reflect the true output power of the amplifier.

Returning to the block diagram of **figure 1**, the lowpass filter smoothes the output from the multiplier to produce a DC output potential that is proportional to the average output power of the amplifier. The time constant of the filter is kept reasonably short so that meter responds quickly to changes in the power level, but with some types of input signal this could give rapid movements from the meter's pointer, making it difficult to read. A peak hold circuit is therefore used between the output of the lowpass filter and the input of the meter circuit. This has a fast attack time but a much

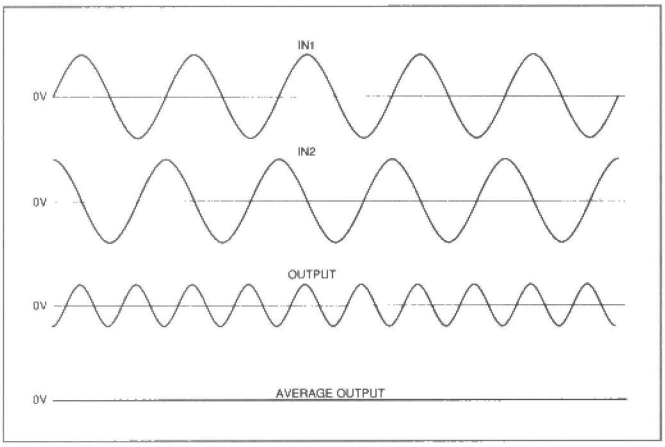


Figure 3: with the inputs 90 degrees out of phase the average output power is zero

lower decay time, so that peak readings are displayed long enough for them to be read easily. The unit therefore reads in terms of what I suppose could be termed peak average output power, but not peak output power. A buffer amplifier ahead of the meter circuit ensures that the peak-hold circuit operates into suitably high load impedance.

Power supply circuit

Ideally the unit should be battery powered so that it is "floating", with no part of the circuit earthed. Unfortunately, the circuit requires dual balanced 15-volt supplies, which makes direct battery power rather impractical. These days there are no difficulties in deriving this type of supply from a low voltage battery using a switch mode power supply. The supply circuit used here (**figure 4**) is based on the Maxim MAX743 switch mode power supply chip, which can be set to provide dual balanced 12- or 15-volt supply rails. In this case 15-volt supplies are required, and the relevant control input at pin 11 is therefore connected to the 0-volt rail. A 4.5-volt battery is not quite up to the task of powering this circuit, but a 6-volt battery would exceed the maximum permissible input potential of 6 volts. The output voltage of a fresh 6-volt battery is actually about 6.4 to 6.5 volts. A 6-volt battery is used to power the circuit, but rectifier D1 is included at the input to provide a voltage drop of about 0.6 to 0.7 volts. This ensures that IC1 is kept within its proper working limits.

This is not really the place for a detailed discussion of switch mode power supplies, but the basic way in which this circuit functions is quite straightforward. Generation of both the boosted positive supply and the negative supply is reliant on the fact that a high reverse voltage is produced when power is removed from an inductor. L1 is the inductor used to generate the boosted positive supply, and an internal switching transistor of IC1 repeatedly connects this across the input supply and disconnects it again. Each time the transistor is switched off, a high positive potential is produced at the bottom end of L1. This is coupled through D2 and into smoothing capacitor C7. D2 prevents C7 from being discharged when the transistor is switched on again. A regulator action is built into the switch mode supply, and this senses the output potential via pin 16. The negative supply is generated in a similar fashion, with L2 being connected across the input supply via another internal transistor of IC1. The top end of L2 goes negative each time this transistor switches off. The negative pulses are coupled to smoothing capacitor C8 via D3, and the feedback input of the regulator circuit is at pin 9. The other capacitors are various decoupling and compensation components.

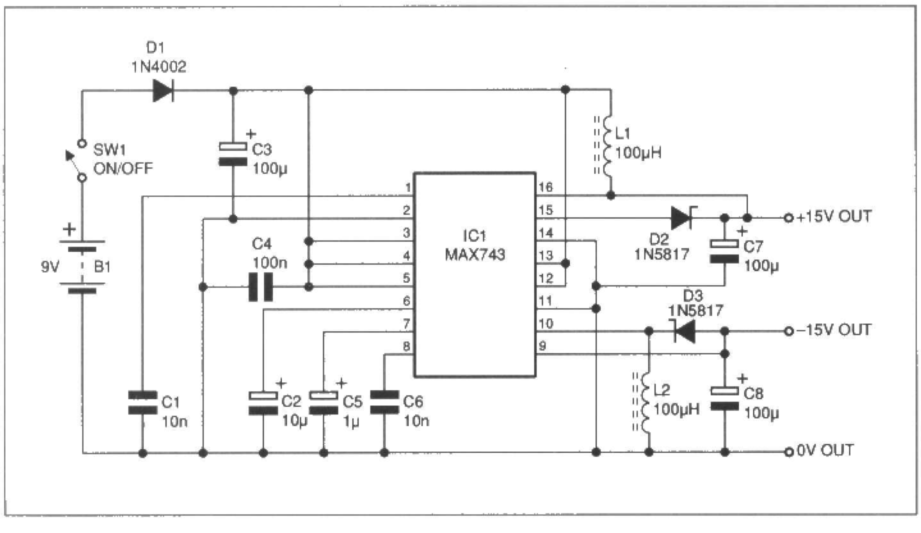


Figure 4: the circuit diagram for the supply voltage generator

The circuit provides well stabilised output potentials, and the MAX743 can handle output currents of up to 100 milliamps. In this case the output current is little more one tenth of that figure, but the voltage step-up provided by the circuit means that the input current is much higher than the output current. The MAX743 provides the high efficiency associated with switch mode supplies, and the drain from the four AA cells is only about 100 milliamps or so. This should give around 20 hours of operation from each set of four AA cells. It would probably be more economic to use larger cells if the unit will be left running for long periods. If mains power is preferred, the easiest solution is to use a 5-volt regulated battery eliminator as the power source. This must be a type having a properly regulated output, and it must be rated at about 150 milliamps or more. Do not use a non-regulated five-volt battery eliminator as this could result in damage to IC1.

The main circuit

The main circuit for the audio power meter project appears in **figure 5**. R1 is the resistor in series with the load, and IC2 is the amplifier at the current input. This is a straightforward non-inverting amplifier having a voltage gain of just under 50. The bifet operational amplifier specified for IC2 provides a good combination of low noise performance and DC accuracy. Its output feeds the appropriate input of the multiplier via a simple lowpass filter (R4 - C9), but this filter has no significant affect at audio frequencies. It is intended to prevent any stray pick up of radio frequency signals from reaching the multiplier and causing erroneous results. The multiplier will accept input signals of up to 10 volts peak (positive and negative), which equates to a peak input current of just under seven amps. Note that the unit can only operate properly if the peak input current is kept within this limit.

Resistors R5 and R6 form the attenuator at the voltage input of the multiplier. The maximum input potential that the circuit can handle is 43 volts peak, or some 86 volts peak to peak. Once again, the unit can only function correctly if the input signal is kept within these limits. The back-to-back zener diodes provide a simple limiter action in conjunction with R5, and limit the maximum input voltage to the multiplier at approx 12.7 volts. C10 is the radio frequency filter capacitor at the voltage input of the multiplier. The multiplier is accurately scaled internally to provide an output potential that is equal to (X * Y)/10. For example, with 6 volts at input X and 5

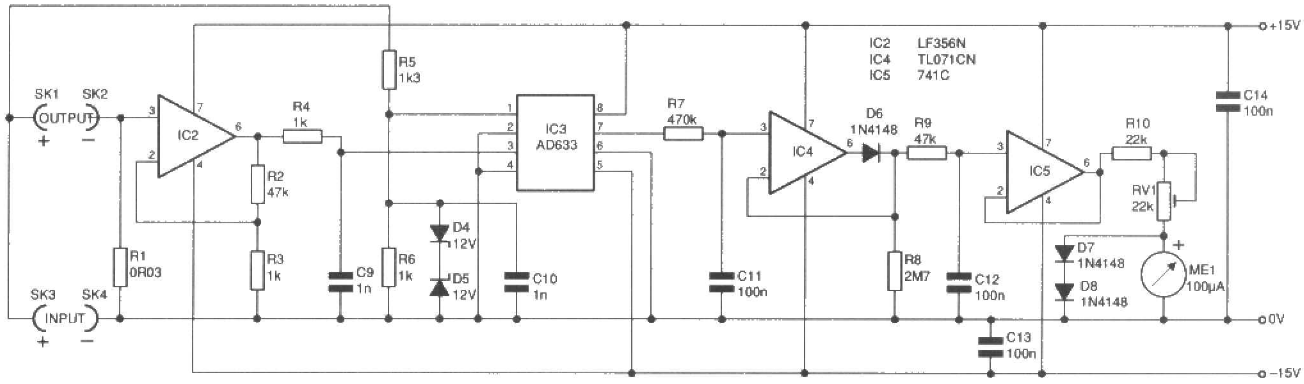
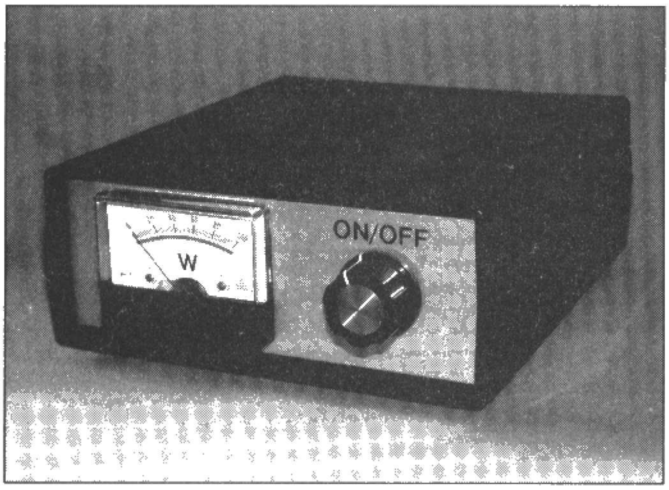


Figure 5: the main circuit diagram for the audio power meter

volts at input Y, 3 volts is produced at the output (6 * 5 = 30, 30/10 =3). The guaranteed precision of the AD633 makes it easy to obtain accurate and repeatable results. Of course, the choice of which input handles the current signal and which handles the voltage signal is purely arbitrary. Whether you multiply voltage by current or current by voltage you end up with the same answer! In this case the voltage signal is applied to the X input, and the current signal is applied to the Y input. The AD633 actually has two sets of differential inputs, but this facility is not required in the present application. Therefore, the two inverting inputs are simply connected to the zero volt supply rail. There is a summing input at pin 6, but this is of no use in this application and is also connected to the 0-volt supply rail. The AD633 is not totally free from the usual DC input and output offset voltages, but these are too small to be worth trimming out. In this application the meter reading falls to an insignificant level long before the offset voltages start to have a noticeable affect on accuracy.

R7 and C11 form the lowpass filter at the output of the multiplier. The time constant of this network has been kept quite short so that the unit has a fast response time. Some users may prefer to use a longer time constant, and this is easily achieved by increasing the value of C11. Operational amplifier IC4 is used in a standard peak-hold circuit which has D6 to prevent capacitor C12 from discharging into the output circuit of IC4. The diode is included in the negative feedback circuit so that the feedback compensates for the non-linearity through the diode. The relatively low value of resistor R9 gives the circuit are fast attack time, and the very much higher value of R8 produces a much slower decay time. With a rapidly changing input level this holds peak readings long enough for them to be easily read. IC5 is used as the buffer amplifier ahead of the voltmeter, and this ensures that the meter circuit places minimal loading on C12. Preset potentiometer RV1 enables the sensitivity of the voltmeter to be varied, and acts as the calibration control. D7 and D8 protect the meter if IC5 should produce an excessive output voltage.



As a point of interest, the circuit is DC coupled throughout, and will therefore measure DC powers that are within its maximum voltage, current, and power limits.

Construction

The component overlay for the printed circuit board is provided in **figure 6**. This also shows the small amount of hard wiring. R1 is not mounted on the circuit board, but is instead connected direct across sockets SK2 and SK4 so that the resistance in series with the load is minimised. This method also avoids having any high currents on the circuit board. Construction of the circuit board is largely straightforward, but bear in mind that the MAX743 is a MOS device, and that the usual antistatic handling precautions must be observed when dealing with it. The AD633 is not a cheap component, and it should be fitted in a holder rather than being a soldered direct to the board. In fact, I would strongly recommend using holders for all the integrated circuits.

Several of the components in the switch mode power supply circuit are worthy of special mention. The MAX743 itself is available from Maplin, as are the 1N5817 Schottky diodes. There are definite advantages to Schottky diodes in switch mode power supplies due to their low forward voltage drops and fast switching times. Ordinary silicon rectifiers would at best give very much reduced efficiency, and might fail to work at all in this circuit. Inductors L1 and L2 must be miniature radial components intended for operation in switch mode power supply circuits. Due to the very low output currents involved here there is no need to opt for high current inductors. In fact high current components are unlikely to fit into the available space. Simple radio frequency chokes are unlikely to work adequately in this application, and could result in damage to IC1. Maplin "miniature radial lead inductors" are used on the prototype, but any similar components should work equally well. Smoothing capacitors C7 and C8 must be low ESR components, and efficient operation of the circuit **cannot** be guaranteed using bog-standard capacitors. **Note that IC1 may be destroyed if the circuit is operated with C7 or C8 absent**. The AD633 is available from Farnell.

Any medium-sized metal or plastic instrument case should comfortably accommodate this project. The meter and on/off switch are mounted on the front panel, and the four sockets are fitted at the rear of the unit. In practice the four "sockets" will have to be spring connectors or some other form of heavy-duty connector that is suitable for use with high power amplifiers and loudspeakers. As pointed out previously, R1 is mounted between SK2 and SK4. There should be no difficulty connecting it reliably, provided the tags of the sockets and the leadouts of R1 are generously tinned with

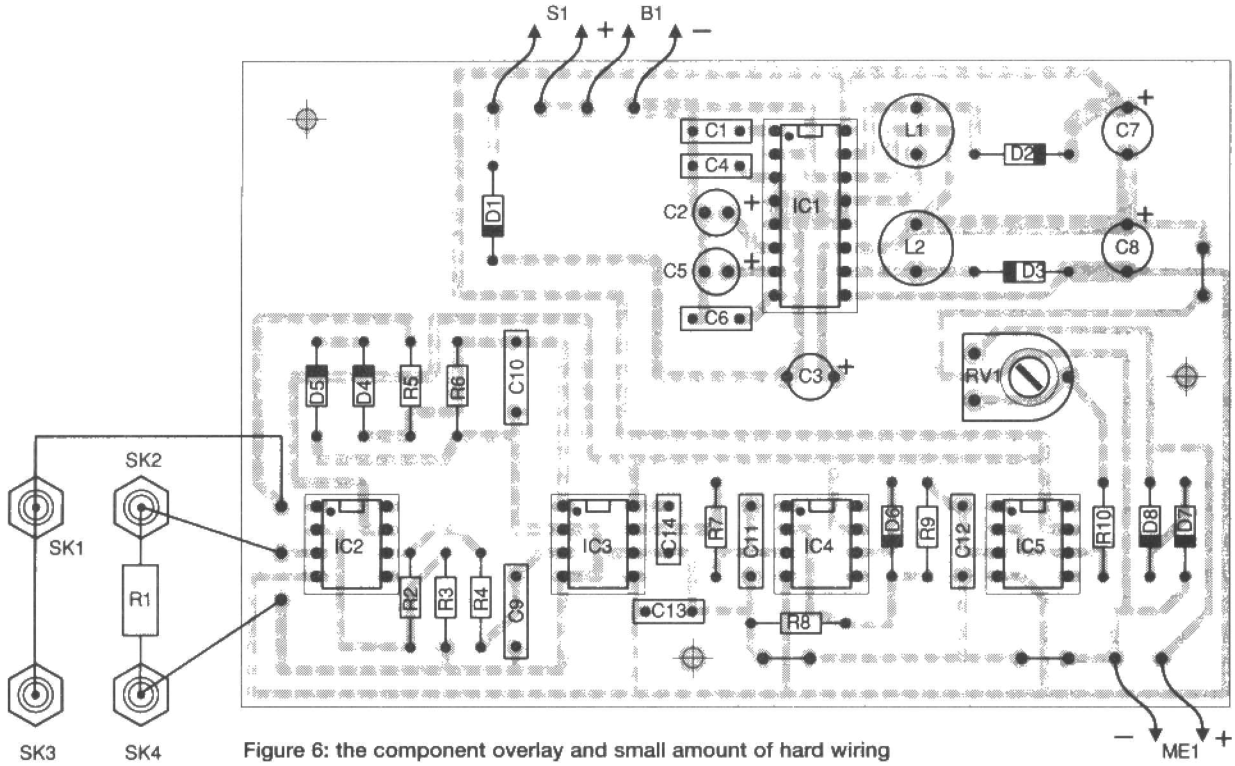
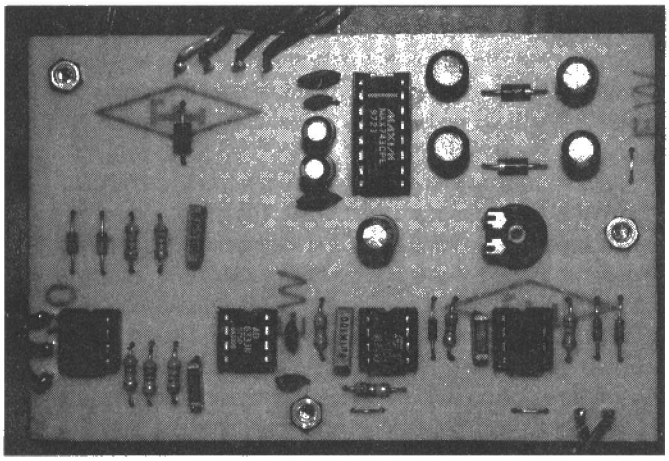


Figure 6: the component overlay and small amount of hard wiring

solder prior to making the connections. Sockets SK1 and SK3 are linked by an insulated wire that must be a heavy-duty type capable of carrying currents of several amps.

Fitting the meter on the front panel is rather awkward, as a large round cutout of about 38 millimetres in diameter is required. The slow way of making this cutout is to use a miniature round file, coping saw, or something of this general type. Unless you are very skilled at this type of thing it is better to cut just inside the line marking the required cutout, and then file out the hole to exactly the required size using a large half-round file. The quick way is to use one of the hole or "tank" cutters that are available from most DIY superstores. These can be adjusted to cover a wide range of hole sizes, and will complete the task in a matter of seconds. However, they are only usable in something like a brace or a power drill that can produce very slow rotation speeds.

The printed circuit board is mounted on the base panel of the case, leaving sufficient space for the battery pack to the rear or to one side, depending on the design of the case. The board is mounted using the usual plastic stand-offs or mounting bolts plus spacers. To complete the unit the small amount of hard wiring is then added.



As described here, the meter can only monitor one output of a stereo amplifier. For stereo operation it is basically just a matter of making up two units, one for each stereo channel. If desired, the two circuits can be housed in one large case, with a common on/off switch having separate poles for the two circuits. It is preferable to keep the two circuits electrically isolated from one another so that problems are avoided when testing awkward amplifiers such as bridge types. This means having a separate battery and switch mode power supply for each channel.

Calibration

In order to calibrator the unit it is necessary to use the basic set up outlined in **figure 7**. The signal generator feeds a sinewave signal into the audio amplifier, which drives a resistive load (not a loudspeaker) via the power meter. An AC voltmeter monitors the voltage across the load so that the audio output power can be calculated. The test frequency should be chosen to be within the frequency range which the AC voltmeter can measure accurately. If the specification of the meter is not available, it is a safe assumption that it will be designed to work well at mains frequencies, and that 100Hz should cause no problems.

To calculate the output power simply square the output voltage and then divide this figure by the load impedance in ohms. In order to calibrate the unit accurately it is necessary use an output power that represents something like 50 to 100 per cent of the full-scale reading, or around 50 to 100 watts in other words. Presumably anyone building a project of this type will have access to suitably beefy power amplifiers.

The resistor used for the dummy load must have a power rating that enables it to take the calibration power without sustaining any damage. In practice this means using several resistors connected in series or parallel, or using a single high-power resistor having a close approximation to the required value. Note that high power resistors are normally reliant on a large heatsink, and should not be operated close to their maximum power ratings unless fitted on a suitable heatsink. The resistance of the dummy load should obviously be approximately equal to the normal load resistance of the amplifier in use. This will normally be either 4- or 8 ohms. An 8-ohm dummy load could consist of eight 1-ohm 10 watt resistors connected in series (giving a total power rating of 80 watts), or a single 10 ohm 100 watt resistor. A 4.7 ohm 100 watt resistor is suitable for amplifiers that require a 4-ohm load impedance. When calculating the output power of the amplifier remember to use the actual impedance of the dummy load and not the amplifier's specified load impedance. To be strictly accurate the 30 milliohms of R1 should be added to the load resistance, but the resistance of R1 is so low that its affect is not really significant. If you have a test meter that can measure very low resistances accurately, it is possible to improve calibration accuracy by measuring the resistance of the dummy load rather than trusting its marked value. The tolerance on high power resistors is normally five percent, incidentally.

As an example of calibrating the unit, suppose that a 10-ohm 100-watt resistor provides the load. Adjusting the controls of the signal generator and the amplifier to provide 30 volts across the load would give an output power of 90 watts (30 * 30 = 900, 900/10 = 90 watts). RV1 in the power meter circuit would then be adjusted for a reading of 90 on the meter.

If required, the full-scale value can be reduced or increased by altering the sensitivity of both the current and voltage sensing circuits. Bear in mind that it is not simply a matter of (say) halving the sensitivity of both circuits in order to double the full-scale value. This is something where the square rule applies, and doubling the full scale input voltage/current quadruples the full-scale power reading. To obtain a full scale value of 200 watts the full scale voltage and current would have to be increased by a factor of 1.414 (the square root of two). This requires R5 to be increased to a value that raises the total resistance through R5 and R6 by a factor of 1.414, which works out at 6.08k. R5 would therefore have to be increased to just over 5k, and 5.1k is the nearest preferred value. The sensitivity of the current sensing circuit can be reduced by lowering the closed loop voltage gain of the input amplifier (IC2) or by reducing the value of R1. Reducing the value of R1 is preferable as it keeps dissipation in this component to a minimum. Finding a suitable component might be difficult, but adding a resistor in parallel with R1 provides an alternative. Adding a 0.05-ohm resistor in parallel with R1 gives a combined resistance that is slightly too low, but raising the value of R2 to 56k would compensate for this.

Reducing the full-scale value to 20 watts requires a five fold increase in sensitivity, which means an increase in sensitivity by a factor of 2.24 (the square root of five) at each input. A large increase in the voltage gain of IC2 is undesirable because it could produce problems with offset voltages and generally compromise performance. Raising the value of R1 is also undesirable, as it could significantly reduce damping of the load. Probably the best solution is to use a mixture of increased gain and a higher value for R1. A value of 0.05 ohms for R1 and 68k for R2 should give satisfactory results. This would accommodate a maximum current of just under three amps. The total resistance through R5 and R6 would have to be reduced by a factor of 2.24, giving a figure of 1.92k. R5 would therefore have to be reduced to 910 ohms, which would accommodate input potentials up to 19 volts.

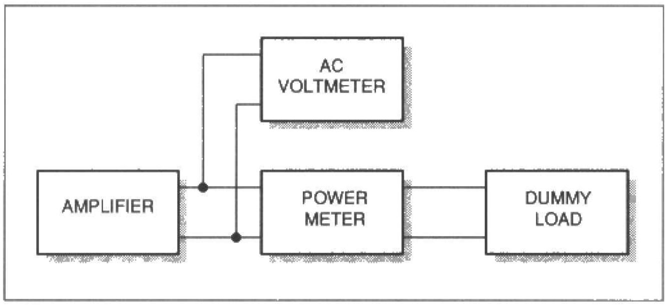
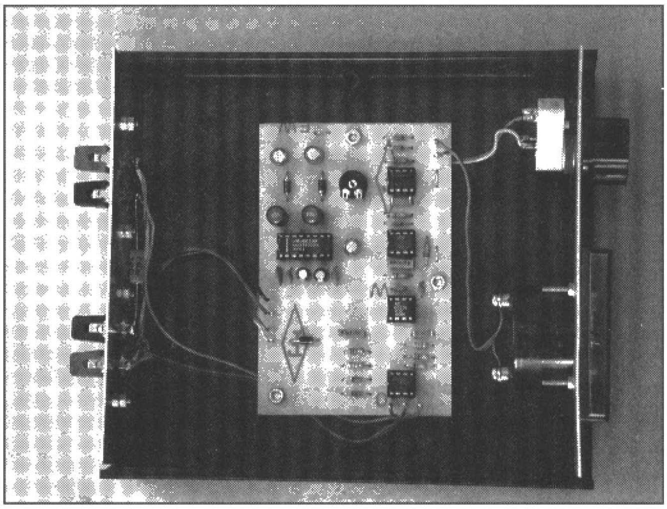


Figure 7: the setup used when calibrating the audio power meter



PARTS LIST *for the Audio Power Meter*

Resistors

All 0.25W 5 percent carbon film unless noted

R1	0R03 2.5W 5 percent silicone coated
R2,9	47k
R3,4,6	1k
R5	3k3
R7	470k
R8	2M7
R10	22k
RV1	22k min hor preset

Capacitors

C1,6	10n disc ceramic
C2	10u 25V radial elect
C3,7,8	100u 16V low ESR
C4,13,14	100n disc ceramic
C5	1u 50V radial elect
C9, 10	1n polyester
C11, 12	100n polyester

Semiconductors

IC1	MAX743
IC2	LF351N
IC3	AD633JN
IC4	TL071CN
IC5	741C
D1	1N4002
D2, 3	1N5817
D4 to D8	1N4148

Miscellaneous

SW1	Rotary on/off switch
ME1	100uA moving coil panel meter
B1	6V (4 x AA cells in holder)
SK1 to SK4	2-way loudspeaker connector
L1, 2	100uH

Plastic or metal instrument case, printed circuit board, 4 x 8-pin dil holder, 16-pin dil holder, control knob, battery connector (PP3 type), wire, solder, etc.

A 4- or 8-ohm dummy load is also needed for calibration purposes.

Car Vigilante

If can park legally without lights, but you are still concerned about the safety of your car, the Vigilante will detect approaching traffic on your side of the road and switch your parking lights on for a predetermined time.

Bob Noyes

The Vigilante was designed to help protect my car from accidental damage when parked at the roadside overnight. The law says that a car can be left at the roadside at night without its lights on under certain circumstances, but even then there is always a risk of another driver not seeing it until too late. Although it is preferable to leave a parking light on overnight, the continuous drain of around 2 amps for up to fifteen hours at a time in the winter can play havoc with the battery, so that the car will not start in the morning - playing havoc with your day.

This project was designed to detect an approaching car from the rear of your car by detecting the oncoming headlights. When the photo sensor detects a light, it switches on the parked car's side lights for a period of time that is pre-settable; both near and offside lights can be activated, although some cars only have an offside parking light facility.

The circuit in detail

The circuit of the Vigilante is shown in **figure 1**, and the component layout in **figure 2**. The Vigilante uses a modern mini photocell which is available from all main component suppliers such as Rapid, Maplin, ElectroMail and so on. Unlike the old "ORP 12" and similar devices that required loads of candle power to turn on or conduct, this little beauty reads over 1 megohm in total darkness, falls to around 20 kilohms at light levels where it is just possible to read its resistance on a liquid crystal multimeter display and falls to below 5k in bright sunlight. Somewhere in that range is near total darkness but a noticeable reduction in resistance when in the outer limits of a car's headlights. To reduce the effect of background light such as moonlight or distant street lamps and to focus the photo cell on to traffic approaching from the rear, the LDR is mounted on the PCB, but at least 20mm from the hole in the outer box (**figure 3**).

When light does fall on the photo cell or LDR I the voltage across it falls; this is due to the potential divider effect of R1, RV1 and the LDR.

If R1 and RV1 stay the same but the resistance of the LDR decreases, the voltage fed to pin 3 of IC1 must fall. R4 produces some level of hysteresis, which stops the Vigilante from triggering several times at dusk and dawn as the natural light levels change slowly.

The effect of R4 is that, starting in dark conditions, the LDR has a high resistance and R1, RV1 relatively low so the output of IC1 is high. R4 is now effectively across R1/RV1, making it even lower. However, when light falls on the LDR its resistance falls below that of R1, RV1/R4 and the output of IC1 goes low, causing R4 for all intents and purposes to

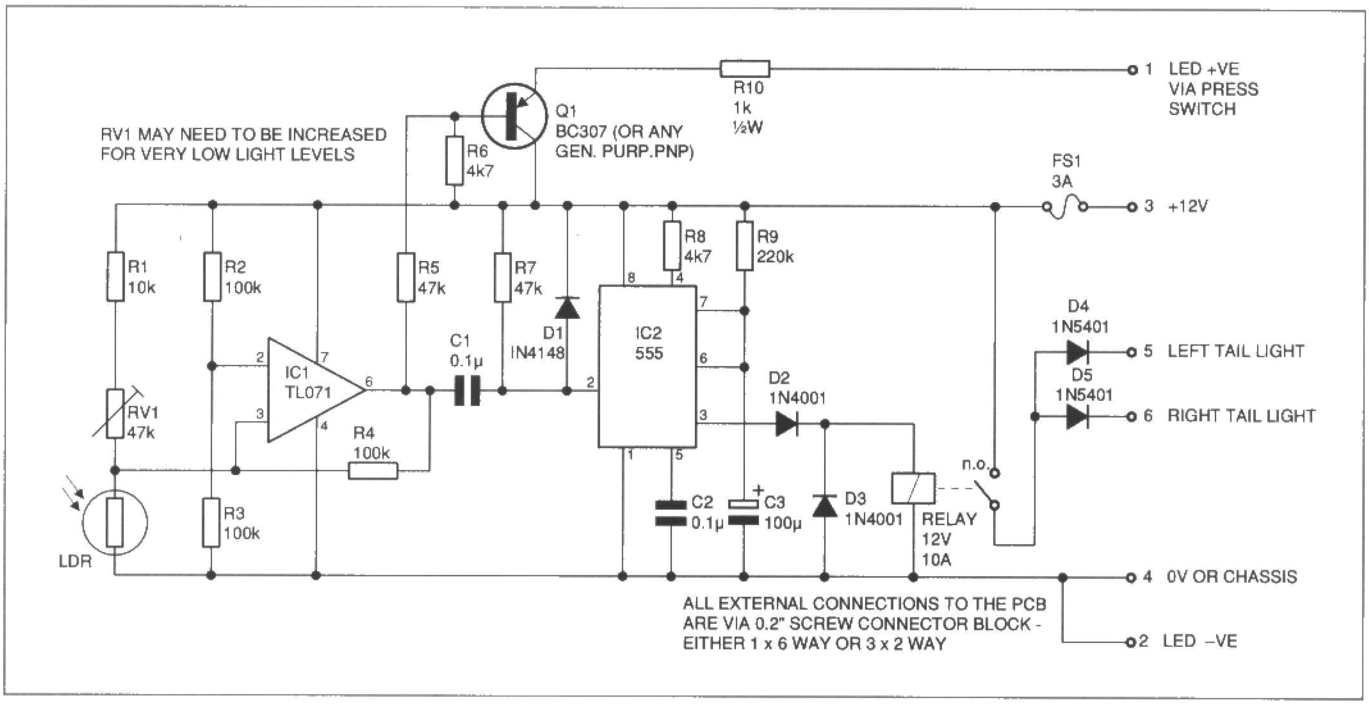


Figure 1: the circuit of the Vigilante. The normally closed contact of the relay is not used

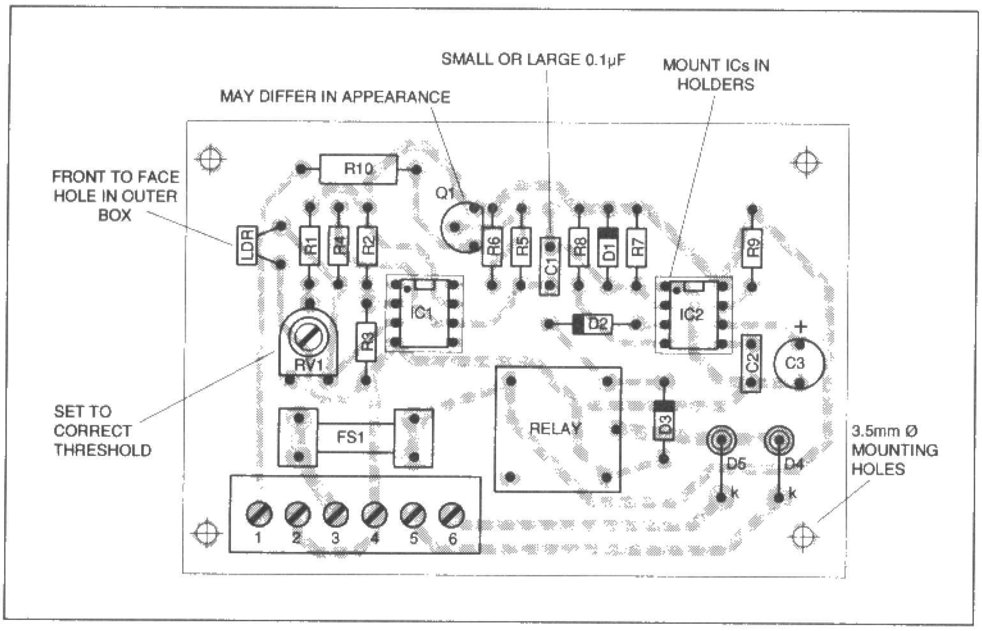


Figure 2: the component layout of the Vigilante pcb

be across the LDR, and reducing its effective resistance in the potential divider. Although this change is relatively small, it has the effect of accelerating the voltage swing at pin 3 of IC1 through the threshold of half volts set by R2/R3 (see **figures 4a and 4b**).

The output of the op amp IC1 is capacitively coupled to the input of IC2. IC2 is a 555 timer wired in monostable mode, the time constant of which is set by R9 and C3; this may be altered to suit prevailing conditions. Reducing the value of R9 shortens the time period that the car's lights are on and increasing it lengthens the time period. IC2 must be capacitively coupled to IC1 or, under daylight conditions, the output of IC1 being low would cause the input pin 2 on the 555 to be low. This would prevent it from timing out, causing the car's lights to stay on, rather defeating the object. Using C1, only a low pulse is generated at pin 2 by the high to low transition of IC1. R7 maintains the high condition the rest of the time, allowing the 555 to time out. D1 prevents any spikes generated from damaging the 555.

The output of the 555 is limited to around 200 mA, which is not enough to power the side lights of a car directly. Around 2 amps steady current is required, so some sort of power switch is needed. Normally a solid state solution is better than one that contains moving parts. Output of the 555, pin 3 could be increased with the use of a power transistor or darlington, and a couple of amps steady state is no problem. However - and this must be taken into consideration - when a light bulb turns on, it draws several times its normal current because the element is cold. This high initial current is why mains bulbs normally fail on switch-on and seldom fail in continuous use. In this case we have four bulbs in parallel, so the initial switch on current could easily be 10 amps or

- **Switches on your parking lights temporarily when traffic is detected from behind**
- **Reduces battery drain when parked**
- **Can be set up at different angles**
- **Wiring for cars with four sidelights connected together and for cars with separate nearside and offside wiring.**

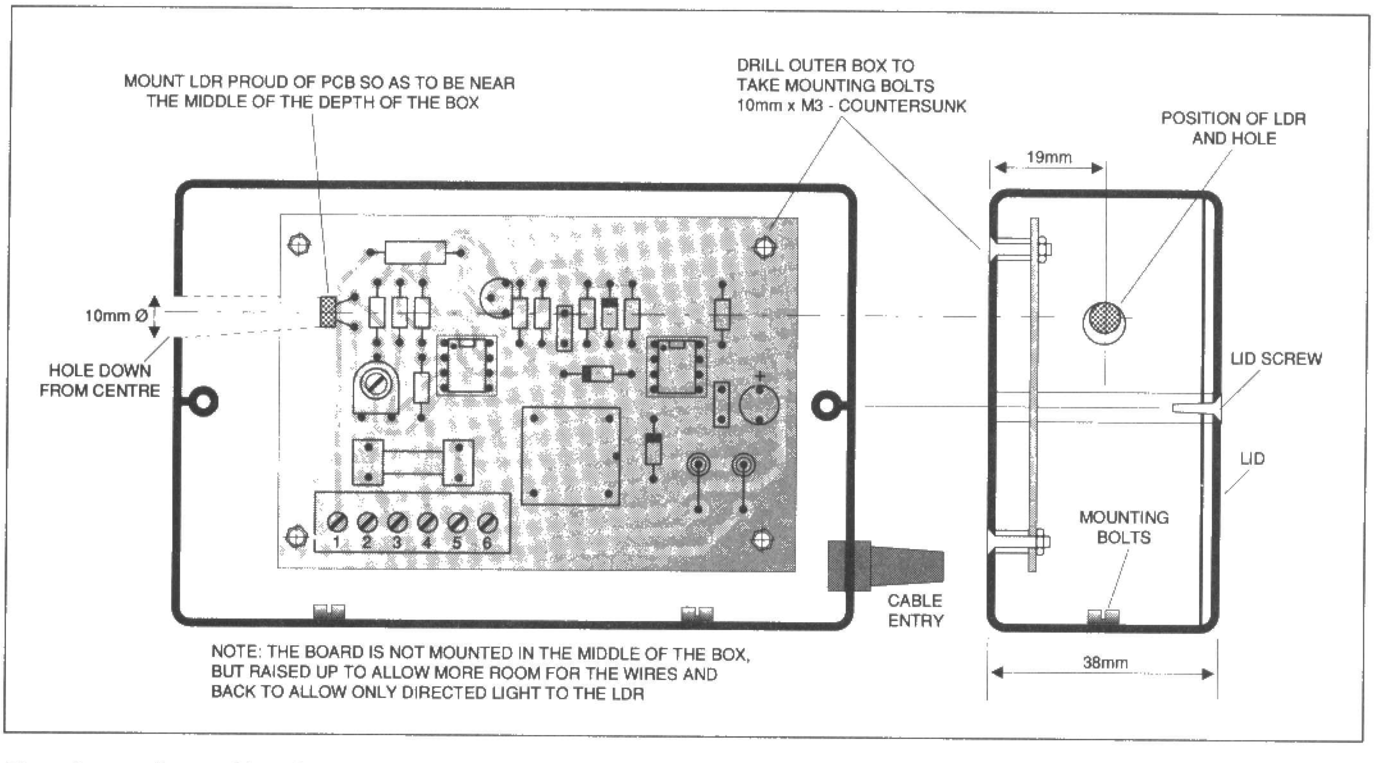
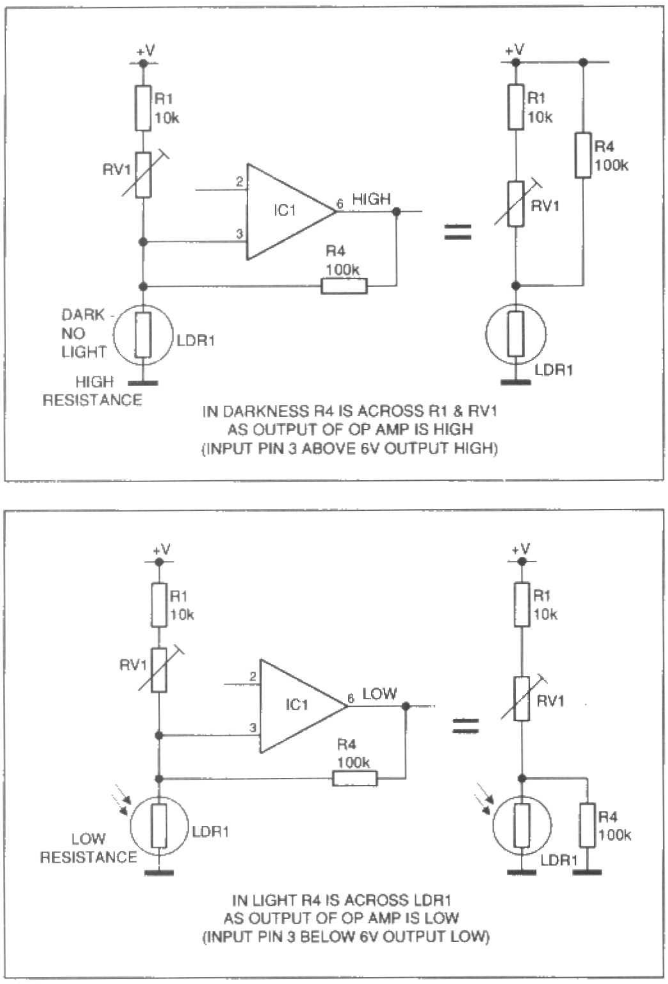

MOUNT LDR PROUD OF PCB SO AS TO BE NEAR THE MIDDLE OF THE DEPTH OF THE BOX
DRILL OUTER BOX TO TAKE MOUNTING BOLTS 10mm x M3 - COUNTERSUNK
POSITION OF LDR AND HOLE
19mm
10mm Ø
HOLE DOWN FROM CENTRE
LID SCREW
LID
MOUNTING BOLTS
CABLE ENTRY
38mm
1
2
3
4
5
6
NOTE: THE BOARD IS NOT MOUNTED IN THE MIDDLE OF THE BOX, BUT RAISED UP TO ALLOW MORE ROOM FOR THE WIRES AND BACK TO ALLOW ONLY DIRECTED LIGHT TO THE LDR

Figure 3: mounting positions for the pcb in its box



IN DARKNESS R4 IS ACROSS R1 & RV1
AS OUTPUT OF OP AMP IS HIGH
(INPUT PIN 3 ABOVE 6V OUTPUT HIGH)

IN LIGHT R4 IS ACROSS LDR1
AS OUTPUT OF OP AMP IS LOW
(INPUT PIN 3 BELOW 6V OUTPUT LOW)

Figure 4a and b: hysteresis around IC1

more, albeit for a fraction of a second, so an extremely high power device would be required. It would have to be driven hard in order to make sure that when turned on there was no appreciable voltage across it, to reduce any heating effects.

A far easier solution in this case is to use a relay, which can be quite small yet switch very heavy currents, with no heatsinking required. The one chosen is a small, relatively cheap and very reliable single pole two-way, although only one way, normally open, is used. The relay's output goes to two forward-biased power diodes, D4 and D5. The reason for this is that in some modern cars the nearside and offside lights are not connected directly together and if connected could adversely affect the electrical system. To prevent this direct connection, these two diodes will allow both sides to light up when powered by Vigilante, but still retain their independence when powered by the car's own electrical system.

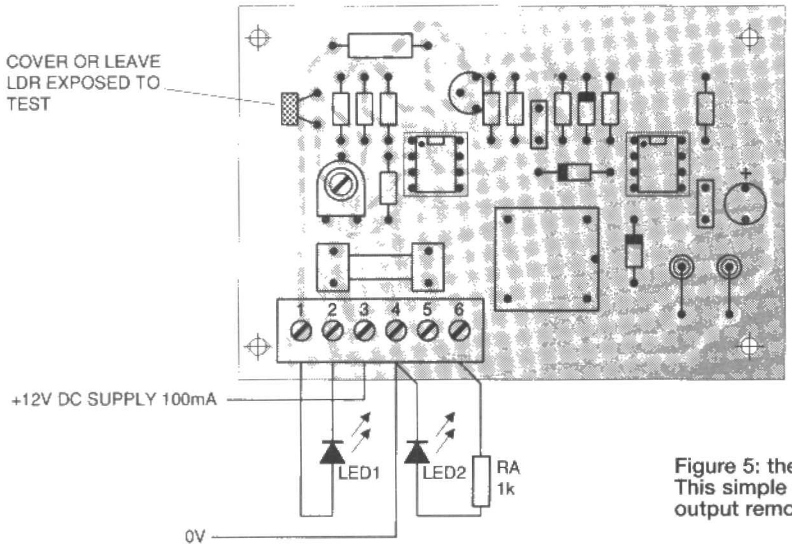
A built-in fuse is a safety precaution and under normal conditions it should never fail, but as extremely high currents are available, one can never be too careful.

Having opted for a relay to do the switching, a couple of safety precautions are required. The working part of the relay is the coil, which is in fact an inductor, although it has a resistance of around 300R. Inductors are strange, because when they are placed across a voltage almost no current flows at once, but then the current builds up to a steady state. Even more strange, when switched off they generate a voltage opposite to the one that has powered them. This voltage produced by the coil is called back EMF (electromotive force), and without the presence of the protection diodes it can give quite a kick. To prevent this induced voltage from doing any damage to the 555 which is powering the coil, two diodes are used. One of these, D3, is across the relay; this is normally reversed biased to the voltage powering the relay. The other, D2, is in series with the relay. This is normally forward biased. These protective diodes prevent the back EMF from getting into the 555 and dump it safely into the supply.

Setting up and testing

After the PCB has been assembled and cleaned it should be inspected for dry joints, unsoldered joints, shorts and all the usual suspects. All components should be checked; the diodes, IC1, IC2, the transistor and C3 are all polarity-conscious and must be mounted the right way round. When you are happy that everything is OK, set RV1 provisionally in the mid-position. If you set it to minimum resistance, even a searchlight aimed at the circuit would not trigger it!

A 12-volt bench supply can be used to power the Vigilante while testing it, because even with the relay



PIN NO.	FUNCTION	CONNECTED TO
1	+VE TO LED	LIGHT MONITOR
2	–VE TO LED	LIGHT MONITOR
3	+12V IN	POWER IN VIA SWITCH
4	0V IN	GROUND OR CHASSIS
5	LEFT OUTPUT	TAIL LIGHT
6	RIGHT OUTPUT	TAIL LIGHT

LED1 – INDICATES OP AMP OUTPUT – DARK OFF
LIGHT ON

LED2 – INDICATES OP RELAY ON – LED 2 ON
RELAY OFF LED 2 OFF

Figure 5: the Vigilante test circuit (not all components shown). This simple test circuit tests the output at pin 6. To test pin 5 output remove wire from pin 6 and connect to pin 5

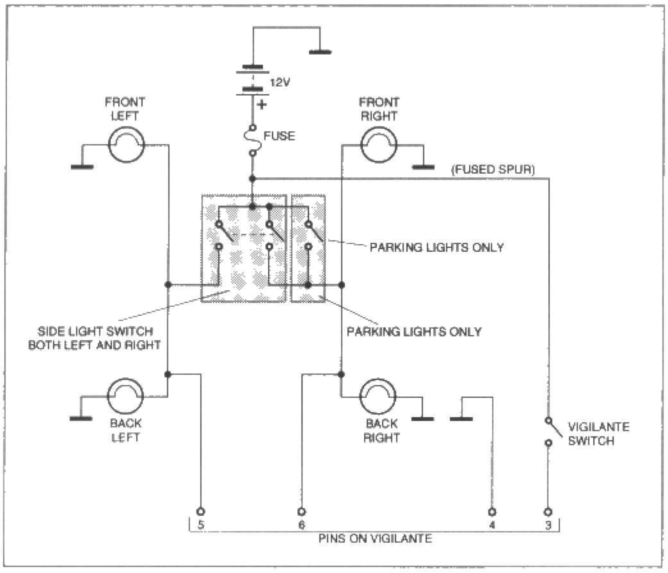


Figure 8: LED1 option, plus ON/OFF LED

energised the total current consumed by the PCB is only about 50mA.

The final setting of RV1 is done basically by trial and error. A simple test circuit is shown in **figures 5 a and b**. To help with setting, LED1, which is powered by Q1, indicates the status of IC1. If IC1's output is high the LED is off, that is, the LDR says "dark". The LED comes on when the LDR senses light (such as an oncoming car's headlights).

LED1 can be permanently wired or can be omitted once the circuit is up and running; another idea, as its only use it to aid with setting up RV1, is to wire it through a press-to-make switch so that it only comes on when the switch is pressed (see **figure 8**).

When the LDR is fully covered, LEDI should extinguish and when a little light falls on the LDR, LED1 should come on. The trial and error bit comes in judging the light expected when the Vigilante is installed. RV1 is adjusted as required (once installed it can be readjusted, all we are doing now is getting the feel for it and testing that everything is working). As soon as the LDR is covered again LEDI goes out immediately. During this time, odd clicks will have been heard from the relay but it is hard to judge what is happening just from them. By using LED2 and the 1k resistor RA (**figure 5a and b**), the relay can be monitored. Once the LDR is triggered by light, both LEDs come on; as soon as the light is removed LEDi goes out but LED2 stays on until the 555 times out; this time-out period is set by R9 and can be changed, as discussed earlier.

Installation

Once the circuit has been tested and a feel for the setting of RV1 established, the Vigilante is ready to be mounted in the car. When it is mounted, the hole for the light to enter must always be pointing in the right direction to detect oncoming traffic. This will vary depending upon the road in question. Traffic may come directly from behind, or, if the road has a bend, it may approach at an angle. Before drilling holes in the parcel shelf or wherever, it is a good idea to wire the Vigilante in and test it under night conditions before finally mounting it. It does not have to be mounted at the back of the car. It can be mounted on the dash so long as it has line of sight out of the back window. Once the position has been chosen, the Vigilante can be wired as required.

On cars with all four side lights connected together only three wires are required (**figure 6a**). On cars with separate wiring for rearside and offside, all four wires are required (**figure 6b**). It is recommended that both rear lights are wired, because if the offside lights only are used, inevitably some twit will try to drive up the inside.

To locate the correct wires in the car's electrical system the manual for that particular car should be consulted. This should not only give the full wiring circuit, but should also give the colours of the wires. If in any doubt, always ask a qualified engineer. After fitting the Vigilante, all the car's electrical system should be checked just to make sure no wires have fallen off or been damaged. Vigilante's power switch can normally be mounted in one of the spare switch positions found in most cars; these are pre-formed and cut in the dash but fitted with a plastic cover. Remove the cover and obtain a similar-looking switch from the dealer garage. A single pole on-off, capable of handling 5 amps, is all that is required (**figure 7**). A monitor LED can be wired as shown in **figure 7**, and some switches already have one built in.

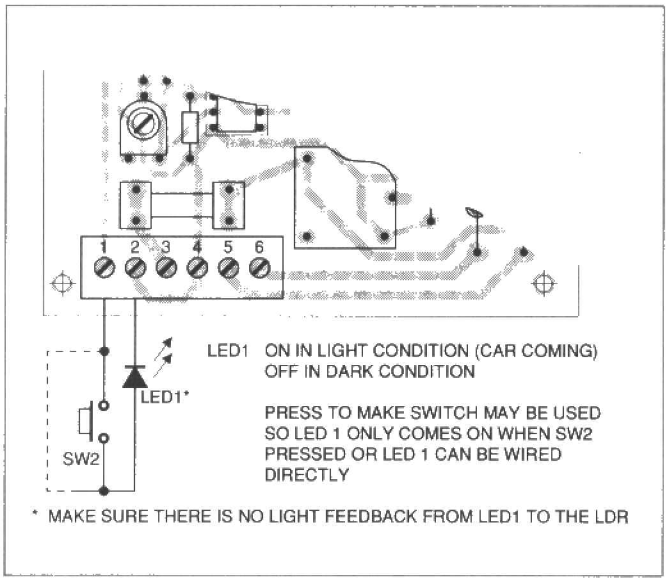

1
2
3
4
5
6
LED1*
SW2
LED1 ON IN LIGHT CONDITION (CAR COMING)
OFF IN DARK CONDITION
PRESS TO MAKE SWITCH MAY BE USED
SO LED 1 ONLY COMES ON WHEN SW2
PRESSED OR LED 1 CAN BE WIRED
DIRECTLY
* MAKE SURE THERE IS NO LIGHT FEEDBACK FROM LED1 TO THE LDR

Figure 6a: wiring to the car: four wires required. Separate left and right car sidelights

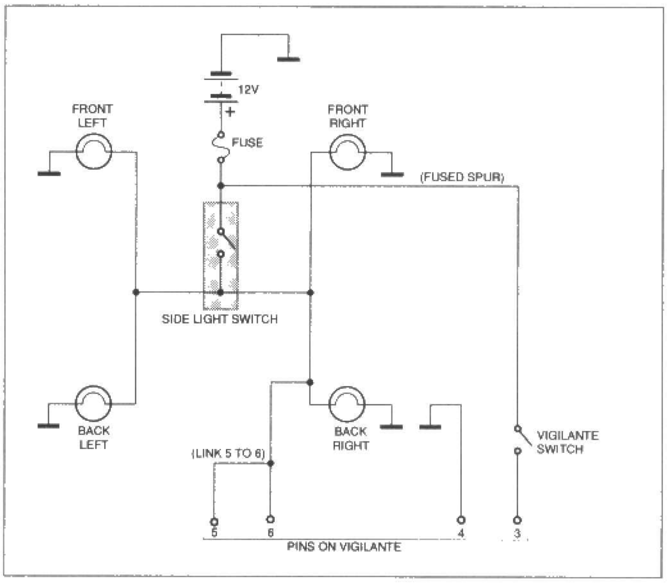


Figure 6b: wiring to the car: three wires required. Left and right lights are joined within the car

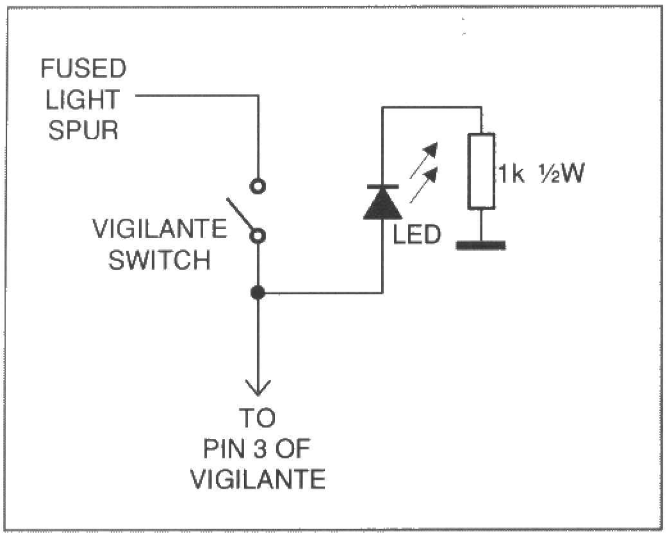


Figure 7: wiring an LED to indicate that the Vigilante is switched on

If there is no provision for extra switches a bracket, bent and drilled, can be made or bought from somewhere like Halfords and fitted under the dash. When wiring, always use a stranded wire well above the expected rating; in this instance use 32/0.2mm, which has a rating of 6 amps, well above the expected current of 2 amps. If the wires have to pass through metal bulkheads or similar, always use rubber grommets to ensure the wires are not damaged by the sharp edges of the metal. Again, if in doubt, always ask a qualified engineer.

It goes without saying that all wires should be hidden for neatness and safety; if any wires are exposed they should be covered in something like spiral wrap to help protect them and provide extra strength.

PARTS LIST *for the Vigilante*

Resistors

R1	10k
R2, 3, 4	100k
R5,7	47k
R6,8	4k7k
R9	220k
R11	1k 0.5 W

Capacitors

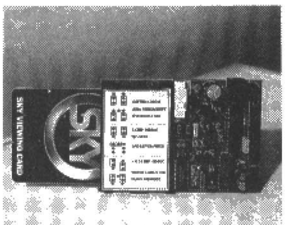
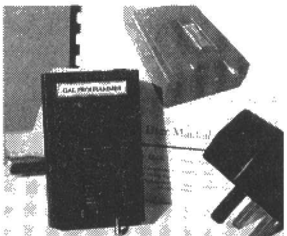
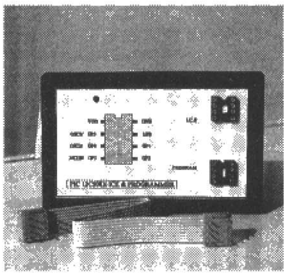
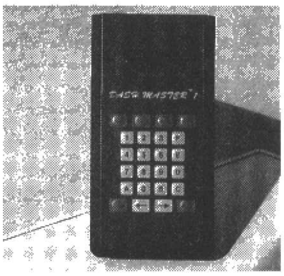
C1,2	100n disk 25V
C3	100n radial 25V

Semiconductors

Q1	BC307
IC1	TL071
IC2	NE555
D1	1N4148
D2,3	1N4001
D4,5	1N5401
LDR1	11k (Maplin AZ 81C)

Miscellaneous

Relay 12V 10 amp (Maplin JM67X)
Box 114mm x 74mm x 38mm (Maplin LF01B)
Connector strip x 3 (Maplin J792A)
LEDs x 2 5mm
Fuse clips x 2 20mm (Maplin KU 27E)

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Timing in Electronics

Part 7: Timing systems

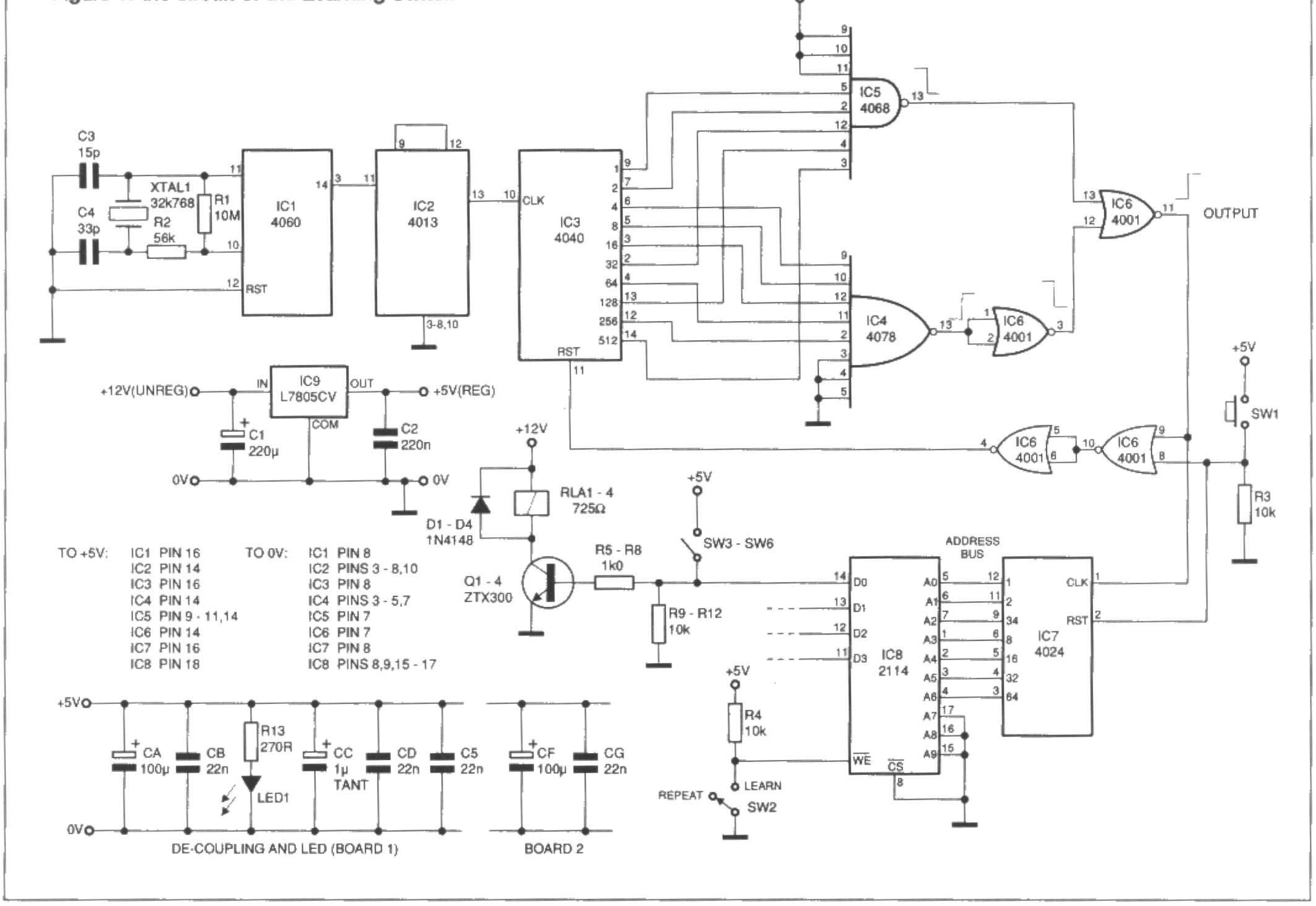
Owen Bishop

This series has described two basic techniques for timing. In one technique, a capacitor is charged either once only (monostable) or repeatedly (astable). In the other, a quartz crystal is made to oscillate at its resonant frequency and the alternating current generated is used to drive a tuned oscillator.

The charging capacitor method is the easiest to use, but the crystal gives the most accurate and stable times. By various methods, often involving a chain of digital counters, the time period may be extended for longer periods of time, or for controlling processes that are to run for relatively long periods. By electronically gating the timer, often using the output from a sensor circuit, it is possible to measure very short periods. The outcome may be a flashing indicator LED, a bleep from an AWD or a numerical result on a 7-segment display. These are the essential elements of a timing system.

A range of elementary circuits has been described in this series, with practical examples. There are many ways of combining these and tailoring a system to suit special requirements. If all you need is a time-keeping electronic clock, it is best to buy one, as there are hundreds of kinds available at low prices. But for special requirements there is scope for designing and building your own system. There is a multitude of ways of fitting together

Figure 1: the circuit of the Learning Switch



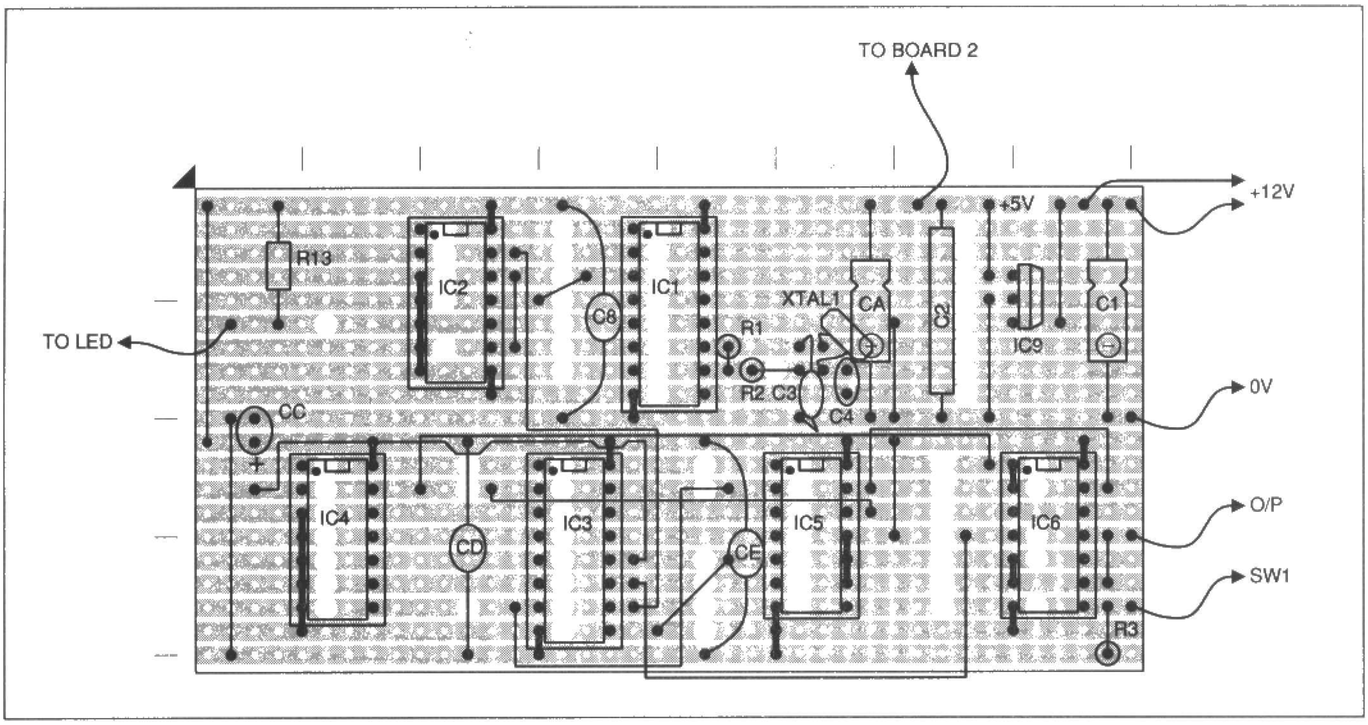
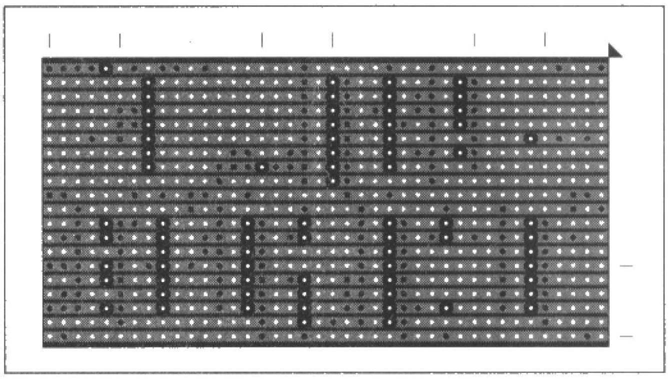


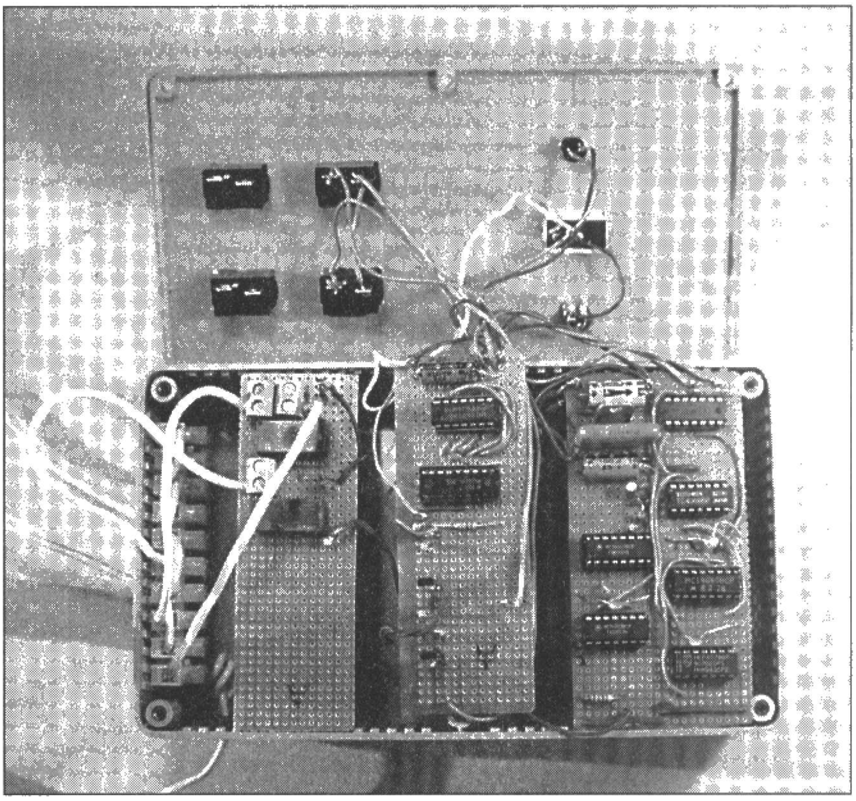
Figure 2: board 1 of the Learning switch: the timing circuits and +5 V supply



the circuits described in this series, and we leave this to your inventiveness and ingenuity. As an example, however, of how to tackle the system design, we have here a practical timing circuit to boost a home security system. It could also have applications in process control because it fundamentally acts by switching on lamps, a TV set, or almost any other kind of electrically-powered device.

Learning switch

The circuit can control up to four devices independently, switching them at preset times, repeating every 24 hours. With home security, the main purpose is to make the house appear occupied when it isn't. Room lighting is switched on and off at irregular intervals, especially during the evening and early morning. The TV or radio is switched on for periods. It can switch other devices such as a vacuum cleaner, or anything else which can be heard or seen from outside the house and which will give a prospective intruder the idea that someone is at home. The fact that the four channels are independently switched gives many different combinations.



The circuit operates in two modes, learning and repeating. In learning mode the devices are switched on and off manually over a period of 24 hours. This programs the timing, the details of which are stored in ram. After 24 hours the device is switched to repeat mode, and then the circuit automatically repeats the settings of the previous 24 hours at the approximate times at which they occurred. To change the sequence at any time, simply switch to learning mode, make the changes manually (no need to do this for the whole 24 hours if you want to leave parts of the programme

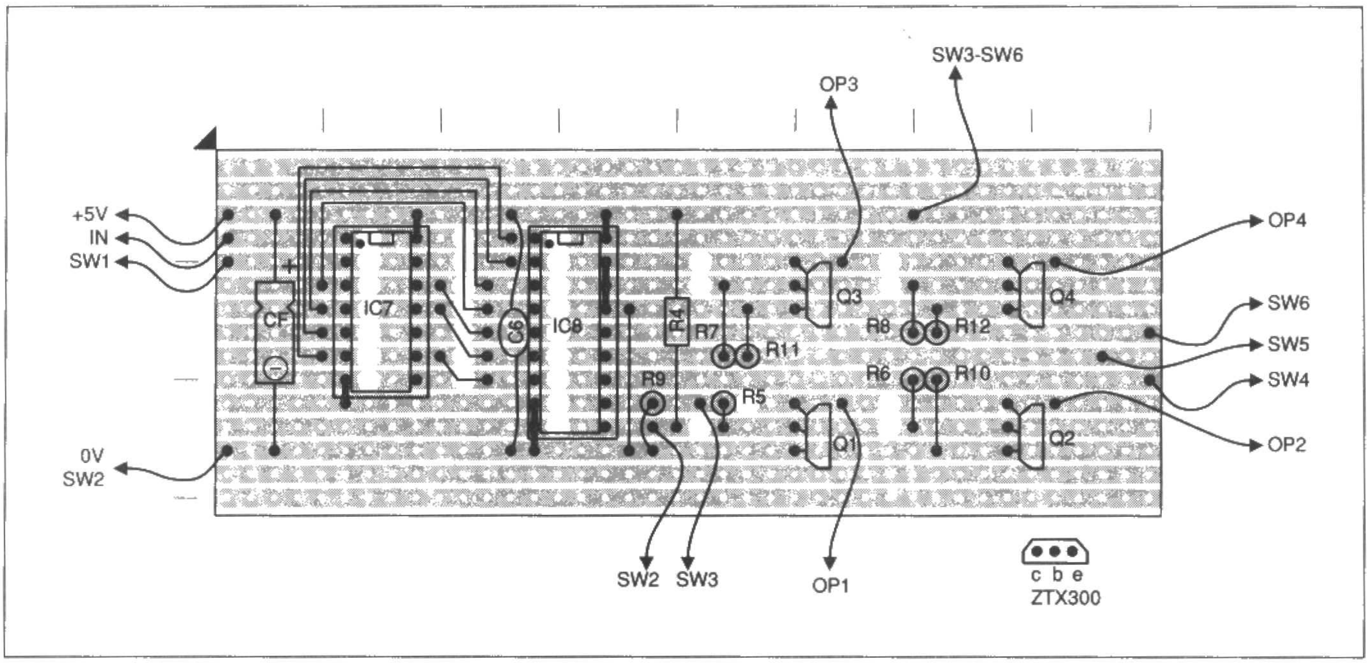
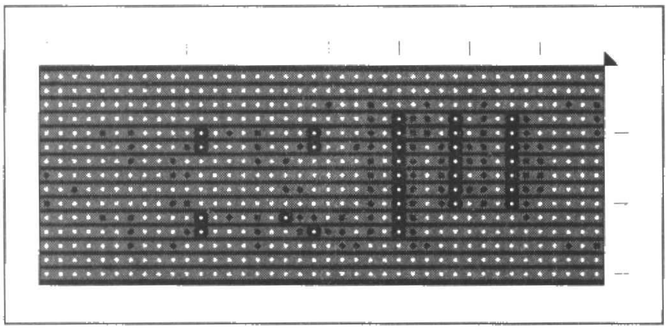


Figure 3: board 2: counter, ram and transistor switches



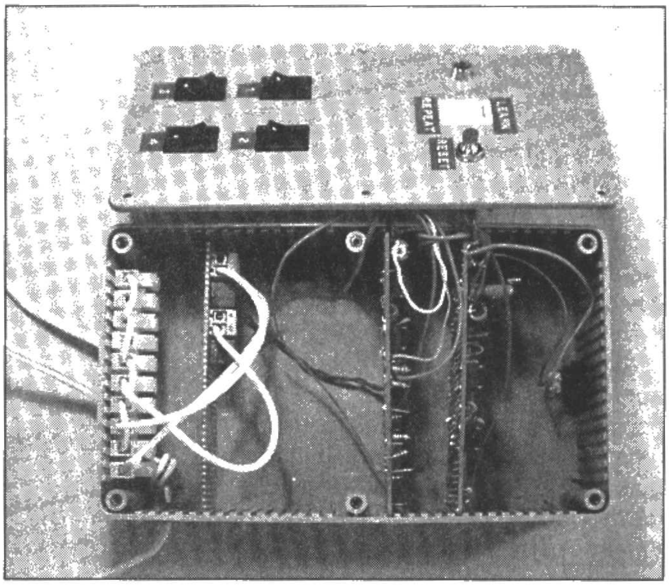
unchanged), then switch back to repeat mode.

System design

Timing is to be repeated every 24 hours for several days or weeks. The timing unit must be a crystal clock to obtain the required precision over a long term. The top third of figure 1 shows that the system includes a 1 Hz crystal clock, consisting of IC1 and IC2, as first described in Part 2 (Issue 7/1998). The circuit must be able to switch the devices on and off for periods appreciably longer than 1 second, but short enough to provide a frequently-changing output. Many automatic timers allow times to be set in quarters of an hour. We need a similar facility in this circuit. The seconds-counting circuit described in Part 6 (Issue 12/1998) allows for periods of up to 34 minutes so this could be used for the next stage. This circuit appears in **figure 1** as IC3, IC4 and IC5. There are two points to notice about the seconds counter: the original design was to count seconds for exactly 5 minutes. It was to sound an alarm or flash an LED when 5 minutes had elapsed, and then needed manual resetting to time another 5-minute period. This slightly different version of the original design makes use of the two spare NOR gates in IC6 to reset the counter automatically when it reaches its preset count. The counter can also be reset at any other stage by pressing SW1.

The other point about this version of the seconds counter is that it is wired for a different period. This design allows for a great deal of flexibility. Here it is wired to run for 675 seconds (11.25 minutes). This may seem like an odd period to work with, but the reason for choosing it more straightforward than it looks. A 24-hour day contains 86400 s, which splits up neatly into 128 periods each 675 s long. And 128 is equal to 27, which has a nice binary feel to it. To wire it to count to 675, we first calculate that 675 is equal to 512 + 128 + 32 + 2 + 1. Expressed as a binary number, this is 1010100011. **Figure 1** shows that digits that are to be zeros at the end of 675 s are wired to IC4 (NOR) while those that are to be '1's are connected to IC5 (NAND). The output at pin 11 of IC6 is normally low but goes high during the 675th second.

In **figure 1** the output of the seconds counter is fed to a 7-stage binary counter (IC7), which is incremented every 675 s. Its seven stages are connected to the seven lower bits of the address bus of IC8, which is a ram ic. In 24 hours the address on the bus increases from 0000000 to 1111111 (0 to 127) addressing each of 128 memory locations in turn. The cycle repeats every 24 hours. This uses only a fraction of the 1024 locations in the 2114 ic but we need only 128. The three upper lines of the



address bus are permanently wired to 0V, as is the chip select (CS-bar) input.

The ram is put into learning (writing) mode by a low logic level at its write-enable (WE-bar) input. This is normally held high by pull-up resistor R4 but can be pulled down by closing SW2.

The memory locations of the 2114 are four bits wide so the data bus has four lines. Each of these has the same circuit attached to it, shown only once in figure 1. In learning mode the data terminals act as inputs. Input is either low, with SW3 open and the input pulled down by R9, or high with SW3 closed. When SW3 is closed and a '1' is being written to ram, the high voltage on the data bus also switches transistor Q1 on, and relay RLA1 is energised. This switches on a lamp or other mains-powered device. During the next 24 hours of learning, the address produced by IC7 cycles through from 0 to 128 and the state of the switches at the end of each 11.25-min period is recorded in ram. Then SW2 is switched to repeat mode. The data terminals now act as outputs, so that the ram now places stored the data on the data bus. At his stage the switches SW3 to SW6 must all be open. A '1' in the data turns on the corresponding transistor and activates a relay. In this way the devices are switched on and off at approximately the same times (to within 11.25 min) that they we switched on and off during the learning phase.

Power supply

The circuit has to operate for days on end, and has to drive relays, so a mains supply is essential. On the premise that it is safer, costs about the same, and is far less hassle to buy the mains PSU ready-made, the circuit is powered from an inexpensive plug-in mains adaptor. This delivers 12 VDC unregulated, with a maximum current of 500 mA, which is ample for this circuit. Most such PSUs have a 2.5-mm DC plug on their outlet so a matching socket is mounted on the wall of the enclosure.

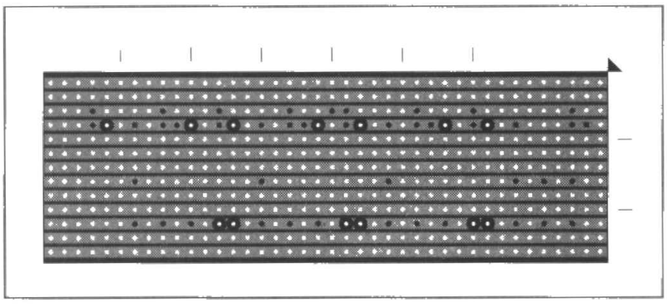
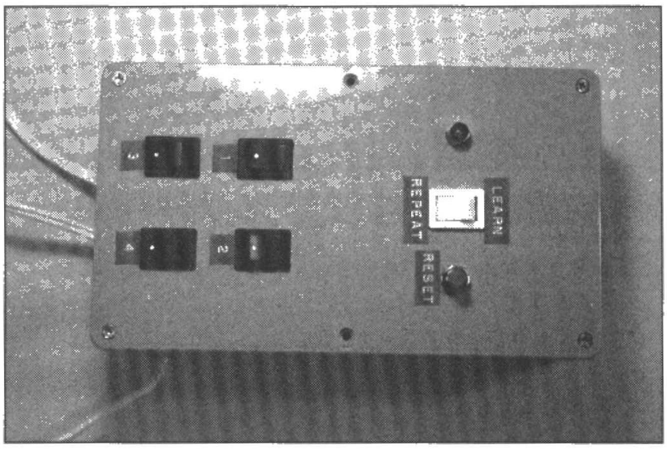


Figure 4: board 3: relays

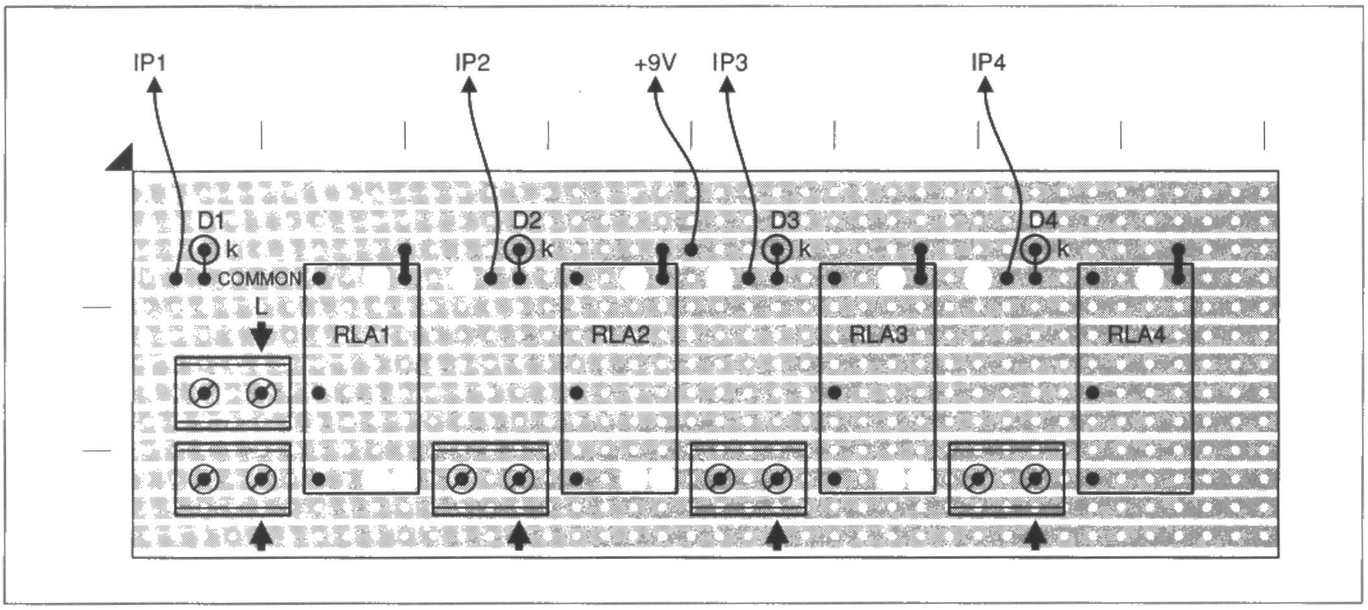


The CMOS logic ics can operate on a wide voltage range, but the 2114 requires 5V regulated, so a L7805 CV regulator is used to supply the logic. The relays are powered from the 12V unregulated supply, which means that switching relays on and off is less likely to produce spikes of the logic supply.

The power for the lamps and other devices comes from the mains, though you could devise a completely low-voltage system if you prefer. If you have not previously built mains-powered circuits, consult a suitably experienced person before embarking on this project.

Circuit boards

The circuit is built on three rectangles of strip-board housed in a plastic enclosure with sides grooved internally to hold the boards. Board 1 (figure 2) holds the 5 V regulator and all the logic as far as the output from the seconds counter. To keep the connections between ics as short as possible, the ics of the timing section are all on the same board, even though this makes the board a bit crowded in places. The board also needs lines for the 0V and 5V supply. Only two signal lines go from



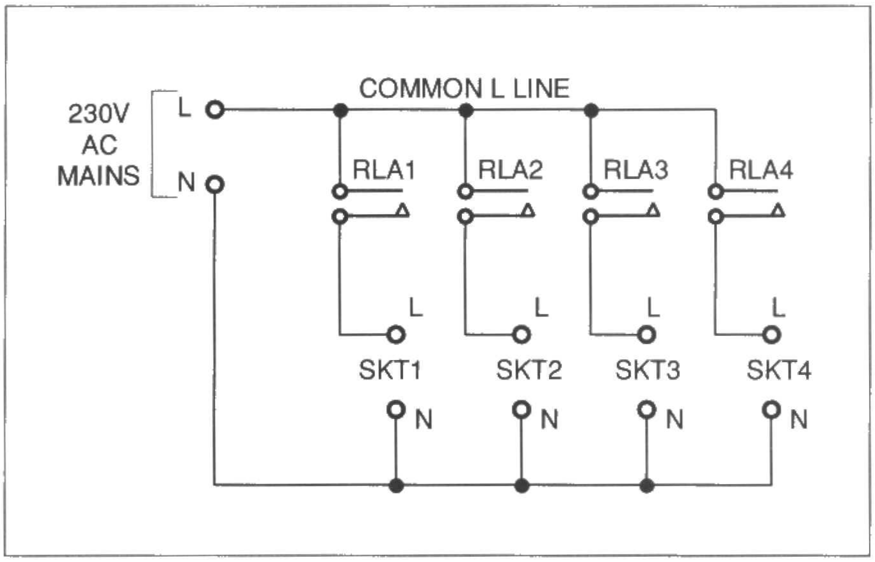


Figure 5: connections between relay contacts and mains power sockets

Board 1 to Board 2 (figure 3), which carries the period counter (IC7), the ram, and the switching circuits. The collectors of the transistors are connected to the relays on Board 3 through the terminal pins OP1, OP2, OP3 and OP4. The switches that control the transistors during learning mode are connected to the pins marked SW3, SW4, SW5 and SW6. Pins SW3-SW6 provides a common connection to the +5 V supply for these switches. Although the circuit will drive up to four devices, there is no need to install all of these at the start. The photos show only two transistors installed, with room to add two more later.

Board 3 (figure 4) holds the relays (two shown installed in the photograph), and care has been taken to keep mains wiring away from the wires of the logic circuits. The connections from OP1 to OP4 on Board 2 are wired to terminals IP1 to IP4 on this board. Note the diodes wired across the coils to prevent damage due to emfs induced in the coils at switch-off. Mains connections to the board are made through screw terminal blocks. These are two-way blocks but only one terminal (indicated by an arrow) is used in each block. Both terminals are soldered to the board to give additional security. The relay contacts are connected electrically as in figure 5. The unit has a lead connecting it to a 13A plug. Up to four leads from the unit to four standard 13A 3-pin sockets into which the controlled devices are plugged. Although not shown in figure 5, these sockets should also be wired to the earth line of the mains supply. Even though the controlled devices may not require connections to earth, it is good practice not to allow unearthed earth terminals in sockets.

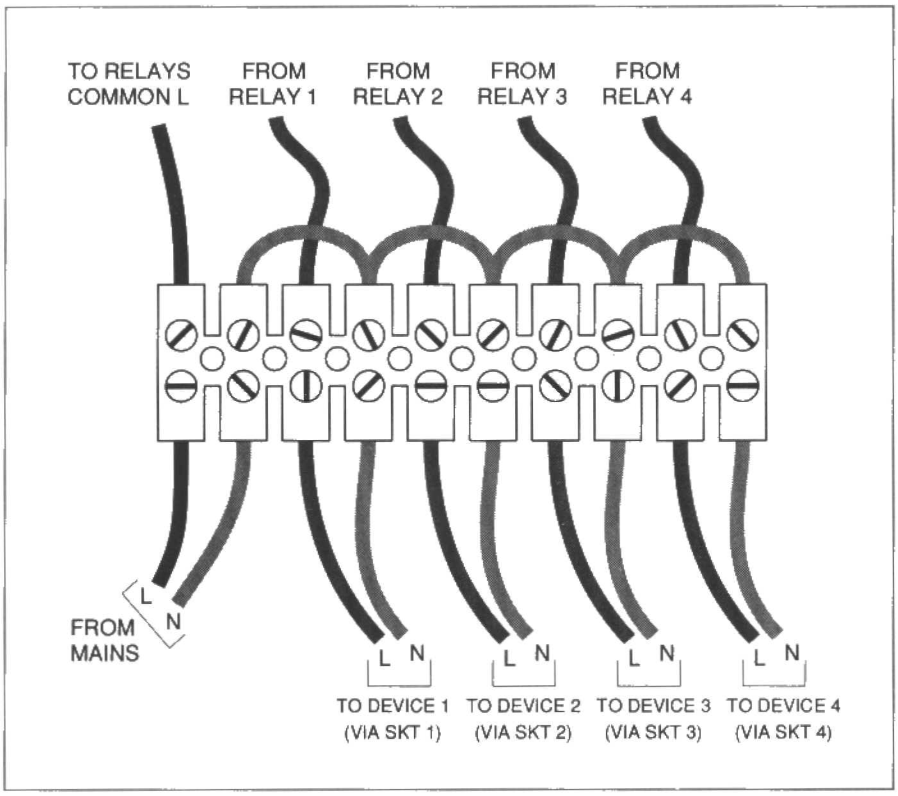


Figure 6: wiring the 10-way terminal block

Construction

The circuit boards are cut to fit securely in the vertical grooves in the wall of the enclosure. A board between 40 and 41 holes wide, tapering slightly toward the bottom, fits neatly into the specified enclosure. Cut the board 41 holes wide, use a file to reduce its width to fit.

Board 1: Build the 5V power supply first (figure 1) and check the output voltage. Next build the 1Hz clock (IC1 and IC2) and check its operation by monitoring the output from IC2 pin 13. Assemble the seconds counter IC3, IC4 and IC4. Temporarily connect pin 11 to the 0V rail, so that you can check that IC3 is counting properly. Then assemble IC6 but check that its logic acts correctly before connecting its inputs to IC4 and IC5 and its output to IC3. Wire SW1 between the terminal pin at S40 and the +5 V line. When all is complete, the output from IC6 pin 11 (the 'OP' terminal pin at P40) is normally low but rises to high for 1 second at the end of each 11.25-second period. Board 1 has a number of decoupling capacitors connected between the +5 V and 0 V lines. The board also has a resistor R13 which is the series resistor for the pilot lamp, LED1.

Board 2: Mount IC7 (figure 3), make the power line connections between this board and Board 1 and wire the terminal pin at E1 to S1. Temporarily connect the terminal pin at D1 to IC2 pin 13. This provides a 1Hz signal for checking the operation of the counter of IC7, so saving time. If all is correct, wire the D1 pin to the O/P pin at P40 on Board 1. Complete the board by adding IC8 and as many sets of transistors and resistors as you intend to install at the beginning. Note that boards 1 and 2 are intended to be positioned in the enclosure so that their component sides face each other.

Board 3: You may prefer to design your own version of this, and make it into a PCB, particularly if you use relays other than those of the specified type. Note that the board receives a +12V supply from Board 1, but no 0 V line. The terminal pins for the relay contacts are close to the terminal blocks on strip L. Run solder between each contact pin and its adjacent terminal block pin. There is only one terminal block for the common connecting strip, strip H. Improve conduction by winding a length of stripped single-stranded connecting wire tightly around each pin in this row and soldering the wire to each pin.

Use light-duty mains cable for making the mains connections to Board 3. All connections run from the board to a 10-way terminal block bolted to the wall of the enclosure (figure 6). If you are including earth wires you way decide to use a 12-way block and allocate two ways for anchoring these.

Otherwise, saw off two ways from a 12-way block. The wires labelled 'from mains' in figure 6 pass out through the wall of the enclosure and are terminated with a 13A plug. Those labelled 'To device n' pass out to 13-amp sockets. The sockets may be mounted on the same board or you may have single or double trailing sockets on the end of each lead. If the leads are reasonably long, some of the lamps may be located in an adjoining room to produce a more realistic effect. The relays specified are rated at 5A, so this load should not be exceeded. The prototype was wired with 3A cable and this is sufficient for powering mains lamps and radio sets. If you wish to switch heavier loads, substitute 12V relays with heavy-duty contacts and redesign Board 3 to suit these relays.

Operation

1. Plug the 12 V power supply into the socket and switch it on. The LED lights. Plug the mains plug into a socket. Plug the devices into their sockets. Switch on the mains.

2. Turn the mode select switch to 'Learn'.

3. Note the time.

4. Use the four control switches to switch the devices on and off at various times, following your normal pattern of use of these devices.

5. 24 hours after the time noted in (3), turn the mode switch to 'Repeat'. The operating sequence of the previous 24 hours is repeated ever 24 hours from now on.

The hardware solution

The circuit described in this part operates as it does because of the logic inherent in its circuits. It is a hardware solution to the problem of making lights and other devices come on at predetermined times. Next month we present a project which does similar things, but based on a software solution.

PARTS LIST

for the Learning Switch Resistors

Resistors

(1 percent metal film 0.25W)

R1	10M
R2	56k
R3, R4, R9-R12	10k
R5-R8	1k0
R13	270

Capacitors

C1	220uF axial electrolytic
C2	220nF metallised polyester
C3	15pF metallised ceramic plate
C4	33pF metallised ceramic plate
CA, CB, CD, CE, CG	22nF ceramic disc (decoupling)
CC	1uF tantalum bead
CF	100uF axial electrolytic

Semiconductors

D1-D4	1N4148 silicon diode
IC1	cmos 4060 14-stage binary ripple counter (with internal oscillator)
IC2	cmos 4013 dual D-type flip-flop
IC3	cmos 4040 12-stage binary ripple counter
IC4	cmos 4078 8-input NOR gate
IC5	cmos 4068 8-input NAND gate
IC6	cmos 4001 quadruple 2-input NOR gate
IC7	cmos 4024 7-stage binary ripple counter
IC8	2114 1024 (4-bit sram
IC9	L7805CV 5V regulator 1A.
LED1	5mm light-emitting diode (in chrome bezel)
Q1-Q4	ZTX300 npn transistor, 500 mA

Miscellaneous

XTAL1	32.768 kHz digital watch crystal
RLA1-RLA4	Omron G6B1114P, single-pole, normally-open, 12V coil (Electrovalue)
SW1	Push-to-make push-button, panel-mounting
SW2-SW6	SPST rocker switch, panel-mounting, snap-in

Standard ABS box, 190 mm (110 mm (60 mm (Electrovalue, 508-942), stripboard (three boards to fit enclosure), 1mm terminal pins (23 off), 2-way pcb mountinhg terminal blocks (301 series or similar, 5 off), 12-way power terminal block, bolts and nuts to secure block, 14-pin ic sockets (5 off), 16-pin ic sockets (2 off), 18-pin ic socket, unregulated 12 V DC mains adaptor, 13A mains plug, 13A mains sockets (4 off), 2-core or 3-core 3A mains cable.

Electrovalue: Unit 5, Beta Way, Thorpe Industrial Park, Egham, Surrey TW20 8RE, UK. Tel. 01784 433604.

ETI Contents Index - 1998

This index is divided into two sections: Technical and Construction, which features all articles on a constructional project or containing construction-related information, and Features, which contains our leading topic features and shorter features

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Back issues of ETI for the previous twelve months can be obtained from **Back Issues, Readers' Services Department, Nexus Special Interest, Nexus House, Azalea Drive, Kent BR8 8HU.** Volume 27 issue 1 is £2.50 plus 70p post and packing. Vol 27 issues 2 - 13 £2.75 plus 70p post and packing.

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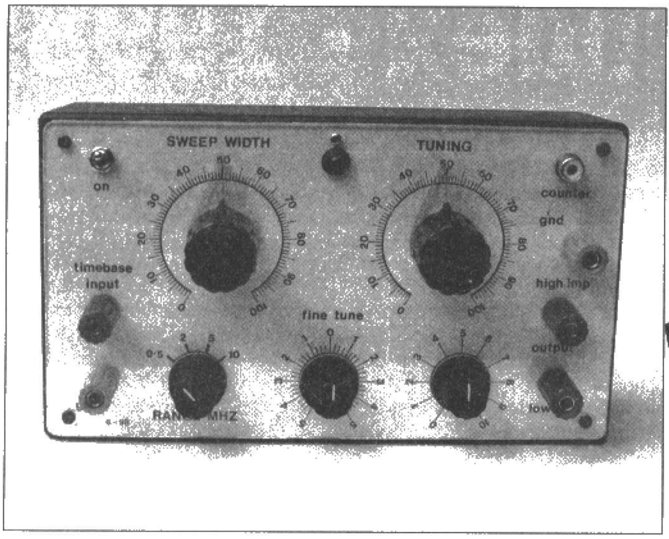


A radio Wobbulator Unit

Alignment of radio receivers can be optimised by means of this low-cost unit which enables their IF response to be displayed on an oscilloscope screen.

Raymond Haigh

Experienced radio set builders can align an IF strip, with a fair degree of accuracy, by ear. One step onwards, connecting a high impedance voltmeter across the AGC line, gives a visual indication of peak response, and alignment is speeded up and becomes more precise.

Using a wobbulator represents the ultimate refinement of this process. An instrument of this kind enables the response curve of the IF strip to be displayed on an oscilloscope screen, and performance can be optimised with extreme accuracy. Bandwidth at various attenuation factors is displayed, permitting a compromise to be effected between sensitivity, selectivity and audio frequency response. While this facility is seldom needed for domestic portables, it does become more important when more complex receivers are under alignment.

Experimenters are making increasing use of low cost, surplus crystals, resonant between about 4 and 10 MHz, in the construction of IF ladder filters. The performance of these filters, especially when they are used for speech-signal reception, is critically dependant on component values and input and output impedances. Using a wobbulator to display the response on an oscilloscope makes it much easier to carry out adjustments.

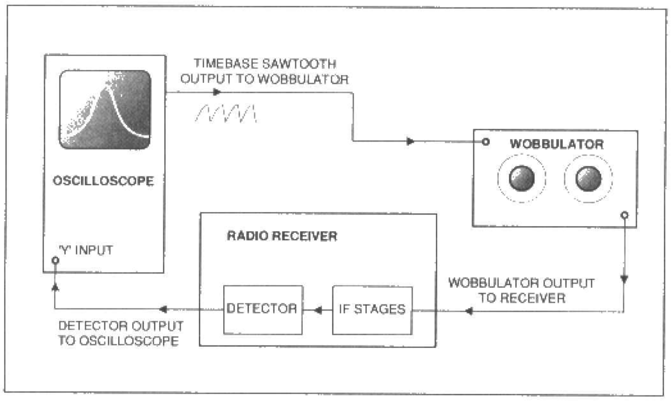

TIMEBASE SAWTOOTH OUTPUT TO WOBBULATOR
WOBBULATOR
OSCILLOSCOPE
'Y' INPUT
RADIO RECEIVER
WOBBULATOR OUTPUT TO RECEIVER
DETECTOR
IF STAGES
DETECTOR OUTPUT TO OSCILLOSCOPE

Figure 1: the connections between the Wobbulator, the radio receiver and the oscilloscope

Principles of operation

A wobbulator is no more than a signal generator giving a frequency which is repeatedly swept over the IF passband of the receiver under test. Frequency variation is controlled by the timebase or horizontal output of the oscilloscope with which the unit is used. In this way the sweep is synchronised, and the oscilloscope displays the response curve of the receiver's IF stages.

Figure 1 shows how the wobbulator, oscilloscope and receiver are connected together. It should be noted that the RF signal is rectified by the detector before being connected to the 'Y' input, and a high performance oscilloscope with an extended frequency response is not required. So long as the timebase sawtooth waveform is available externally, almost any basic oscilloscope will suffice.

Varying the frequency

Early instruments of this kind used a motor-driven tuning capacitor to shift the frequency of the oscillator. During the valve era, reactance valve circuits were developed, and this enabled the frequency to be varied electronically. Subsequent advances in semiconductor technology produced the varactor or varicap diode, which exploits the way the capacitance of a semiconductor junction (and hence the frequency of the tuned circuit in which is it used) can be changed by varying a reverse bias voltage.

Frequency can also be shifted by varying the supply voltage to the valve or transistor in the oscillatory circuit. This method carries the risk of introducing amplitude modulation (which would distort the oscilloscope display), and it can be difficult to secure sufficient swing. It is, however, effective as a means of varying the frequency of a multivibrator, and oscillators of this kind, which are tuned by RC rather than LC circuits, have formed the basis of some wobbulator designs intended for the alignment of 450-470 kHz IF stages.

Unfortunately, the operation of multivibrators becomes less predictable as frequency is increased, and it was decided that using a varicap diode to shift the frequency of a conventional Hartley oscillator would ensure more repeatable results in a unit designed for operation up to 15MHz.

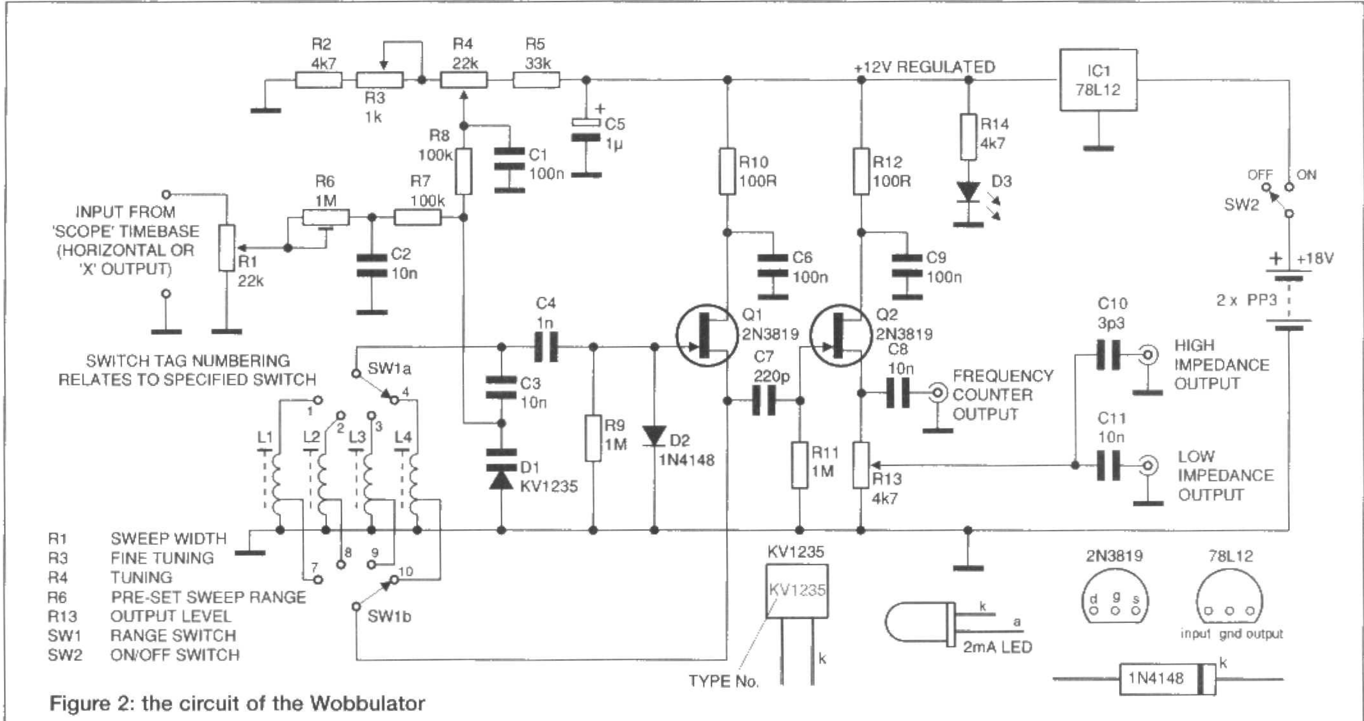


Figure 2: the circuit of the Wobbulator

The circuit

The circuit of the wobbulator is given in **figure 2**. The fet Q1 is the active device in the Hartley oscillator circuit which is tuned by inductors L1-L4, and a varicap diode, D1. Gate and source of Q1 are connected to the appropriate coil by range switch SW1.

C3 is a DC blocking capacitor for the reverse bias which tunes the varicap diode, and R9 ensures the correct biasing of Q1. Diode D2, stabilises the bias on Q1 and ensures consistent operation and constant output levels across the four switched ranges. R10 and C6 decouple the oscillator from the supply rail.

The output is taken from the source of Q1 and connected to the gate of Q2 via coupling capacitor C7. Source-follower (or common drain) buffer stage Q2 minimises loading on the oscillator and isolates it from the equipment under test in order to prevent any frequency pulling or other disturbance to its operation. R11 ensures the correct biasing of the buffer stage, R12 and C9 decouple it from the supply line, and the output is developed across source load potentiometer R13.

The potentiometer R13 sets the output at an appropriate level. The low value DC blocking capacitor C10 enables the signal to be injected into a high impedance circuit without excessively disturbing its operation. The output via the higher value blocking capacitor, C11, should be chosen when the injection point presents a low impedance, or when the connecting lead must be screened. Constructors who have access to a frequency counter may wish to use it with the wobbulator, and the counter output socket is connected to the source of Q2 via blocking capacitor C8. (The wobbulator output potentiometer is usually turned well down, and the voltage on the slider is not sufficient to trigger most counters.)

Current drawn by the unit is approximately 10mA, and operation by batteries is, therefore, perfectly feasible. Bias for the tuning diode is derived from the power supply rails, and precautions must be taken to ensure that tuning doesn't drift with falling battery voltage. Accordingly, two PP3 batteries are connected in series to give a nominal 18V, and this is held at 12V by means of the 100mA regulator, IC1. Tantalum capacitor C5 is included to bypass any electrical noise generated by the regulator ic.

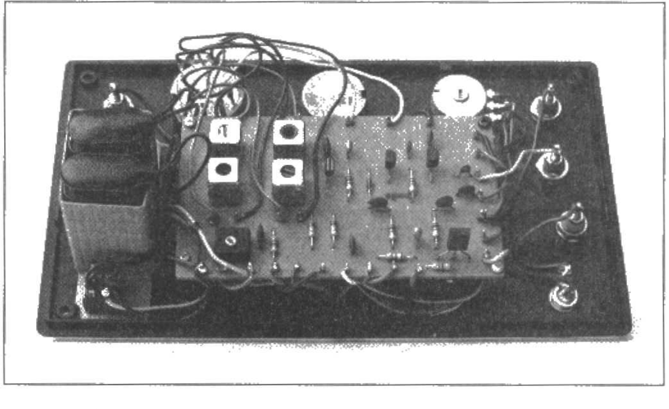
Equipment of this kind can be inadvertently left switched on. Low current LED D3 and dropping resistor R14 are included to minimise the chance of this happening.

Oscillator tuning

Wobbulators often incorporate a conventional air-spaced variable capacitor to set the oscillator to the IF centre frequency. A varicap, wired in parallel with it, and coupled to the oscilloscope timebase, produces the frequency sweep.

Silicon rectifier diodes (such as the 1N4001) are sometimes deployed as varicaps, as they also exhibit a capacitance change across the junction as a reverse bias is varied. However, using diodes of this kind can reduce the 'Q' factor of the tuned circuit and inhibit oscillation, especially when more than one is used to increase the capacitance swing.

This wobbulator is tuned, and its frequency shifted, by a single varicap diode of the type developed for medium wave receivers. These devices provide a capacitance swing of around 450pF with a tuning voltage range of 2 to 9V, and exhibit a 'Q' factor of at least 200. Although they are more expensive than a rectifier diode, the need for a conventional tuning capacitor is avoided and the overall saving in cost is



The interior assembly and PCB of the wobbulator

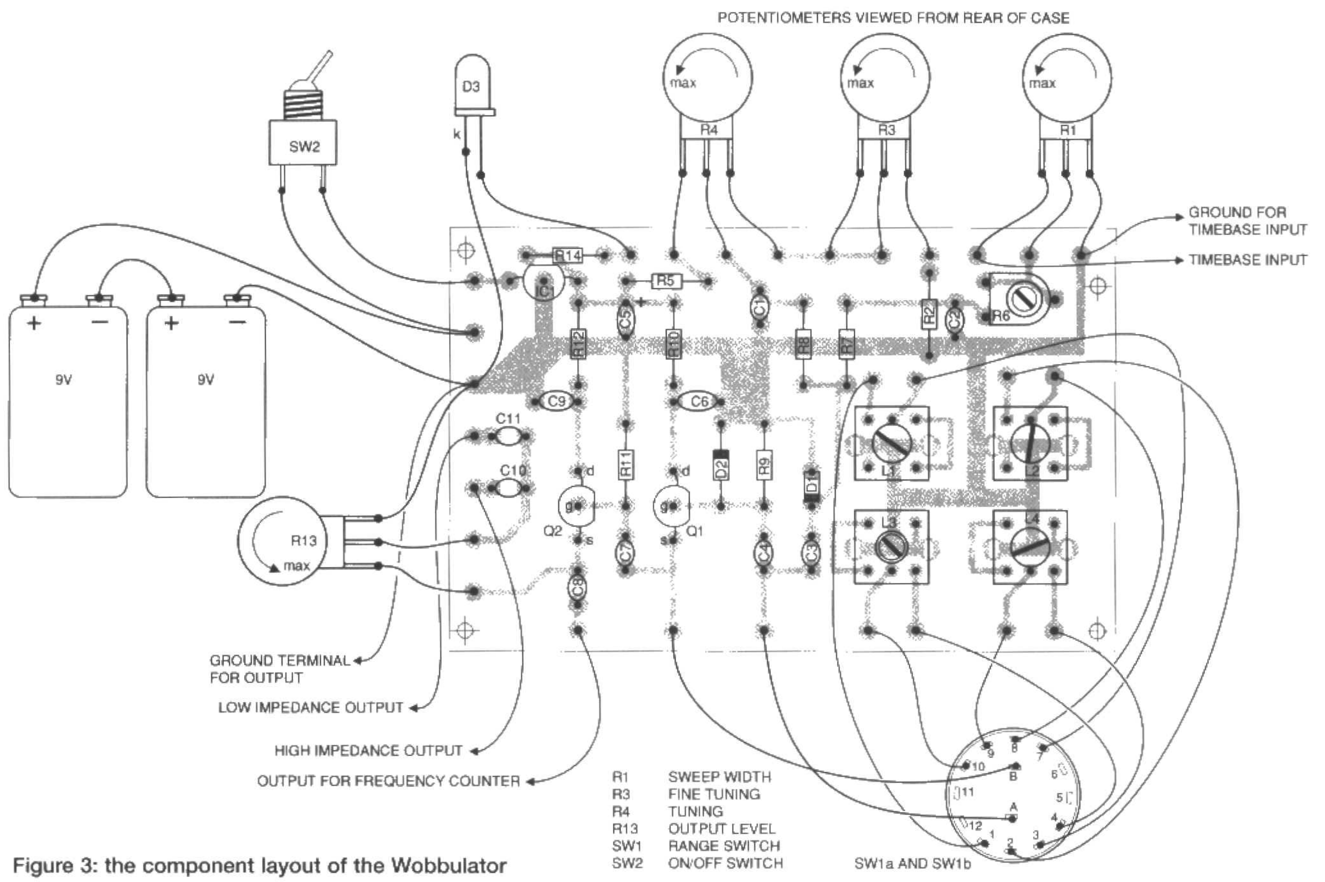


Figure 3: the component layout of the Wobbulator

significant. More important, wide frequency sweeps are easy to obtain, and the full IF passband, together with a portion of the RF spectrum on either side, can be displayed.

The capacitance/tuning voltage relationship of the chosen diode is very linear up to about 6V. Between 6 and 9V the rate of capacitance change falls. Below about 1V, the 'Q' factor of the diode reduces.

Tuning bias for the diode is taken from the slider of potentiometer R4, and fixed resistors R5 and R2, limit the voltage swing from around 1V to 5.5V. Potentiometer R3 acts as a fine tuning control, and C1 eliminates potentiometer wiper noise.

Timebase input

Potentiometer R1 determines the amplitude of the sweep input voltage, and pre-set resistor R6 enables the range of this control to be adjusted to suit most modern oscilloscopes. The timebase sawtooth voltage can be checked by turning down the time/cm controls until the spot drifts slowly across the screen. The pointer of a DC voltmeter, connected between the oscilloscope timebase output and ground, should then move slowly enough for the minimum and maximum sweep voltages to be read off. The oscilloscope used with the prototype wobbulator generated a sawtooth waveform running from around 15 to 25V. If much higher voltages than this are encountered, wire a resistance in series with R1 in order to reduce the input to the required level.

Again, C2 eliminates potentiometer wiper noise, and R7 and R8 isolate the varicap diode, at signal frequencies, from the tuning voltage networks. (The diode passes virtually no current, so the isolating resistors have no effect on the tuning voltage.)

Components

The Toko coils, varicap diode and low current LED can be obtained from Cirkit Distribution Ltd., Park Lane, Broxbourne, Herts., EN10 7NQ. Tel. 01992 448899.

The varicap diodes are supplied in snap-apart packs of two (KV1236) or three (KV1235) for ganged receiver tuning. The price of both packs is currently the same, so constructors may as well purchase three diodes and put the spares to good use in other equipment. The less expensive BB212, also listed by Cirkit and available as a two-pack, was not tried, but it should prove suitable.

An inexpensive, two pole, six way plastic-cased Lorlin rotary switch can be used for SW1. This item, together with the remaining parts, is available from a number of suppliers, including Cirkit.

Construction

All of the components, with the exception of the switches, potentiometers, and the LED indicator, are mounted on a small PCB. The component side of the board is illustrated in **figure 3**. Vero pins, inserted at the lead-out points, will simplify the task of wiring up the off-board components.

It is convenient, with equipment of this kind, to have the input and output sockets mounted on the front panel. This does necessitate a slightly larger case, but the unit can still be accommodated in a standard plastic box with external dimensions of 196 x 112 x 62mm.

Figure 4 shows the front panel layout adopted for the prototype unit. The dials and control annotations are marked out on white card using rub-down transfers, and the finished panel is protected from soiling by a sheet of thin perspex (the type of material used for DIY double glazing). For reasons

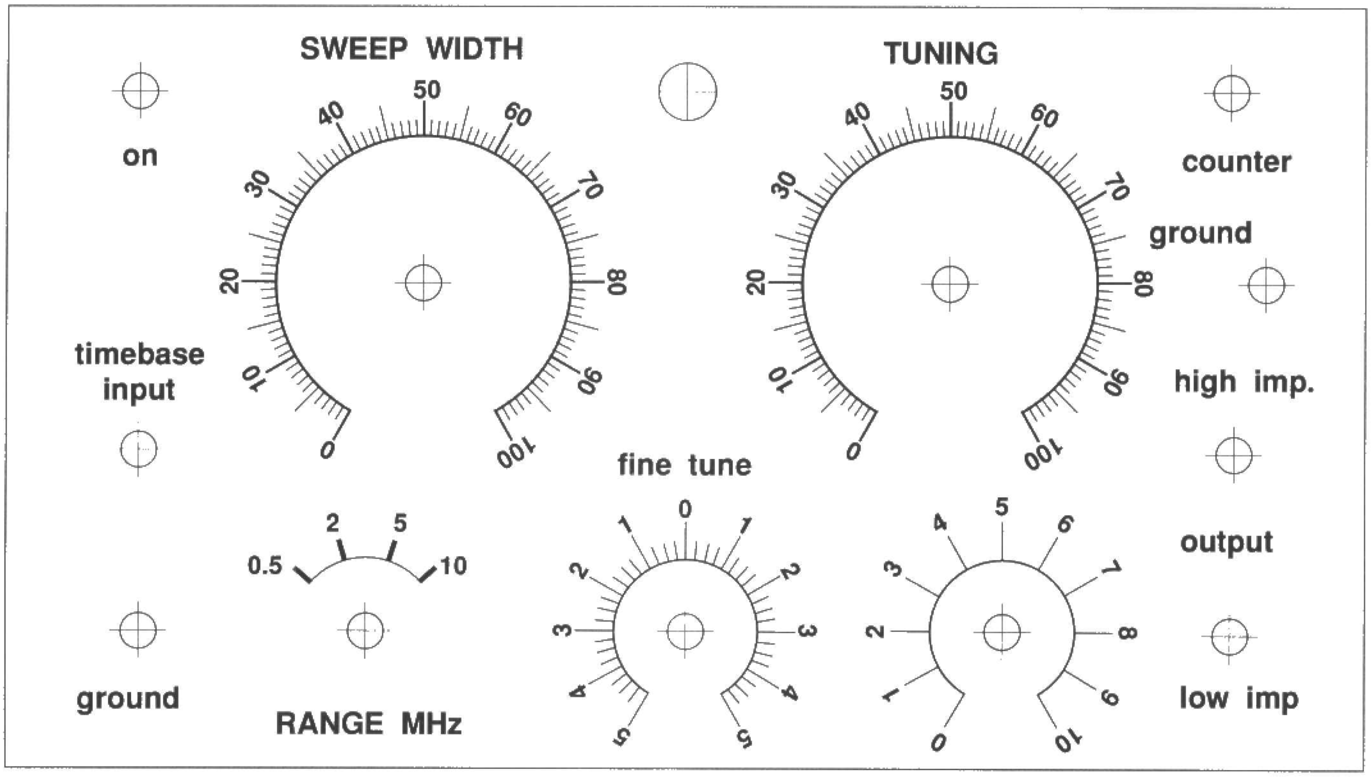


Figure 4: the front panel of the Wobbulator prototype, actual size.

which will become clear later, it is neither feasible nor necessary to calibrate the tuning dial.

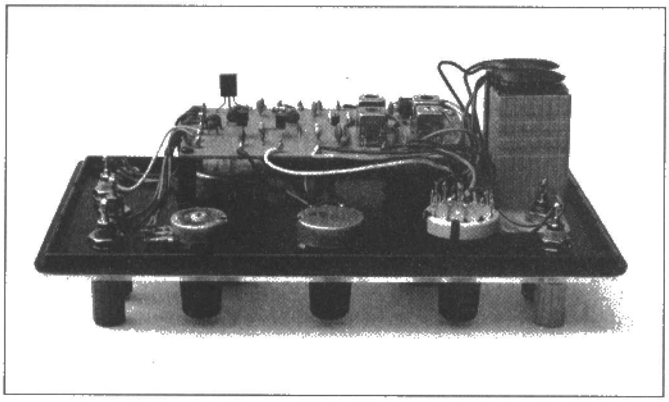
Switches, potentiometers, terminals and circuit board are all mounted on the lid of the box and the assembly is depicted the photographs. The battery holder is formed from scrap aluminium sheet and held in place by the on/off switch bush and one of the terminals.

Remember to check the orientation of semiconductors and the tantalum capacitor, and to check the PCB for poor soldered joints and bridged tracks, before mounting it in position.

Setting up and testing

Connect up the batteries. Current consumption should be in the region of 10mA and the voltage at the output of IC1 should be precisely 12V.

Set R1 and R3 to mid travel and use a radio receiver or frequency counter to check that the oscillator is working on all four ranges and can be tuned by R4. With no input from the oscilloscope timebase, coverage of the prototype unit is as follows:



The assembly showing the knobs in place on the front panel

Range 1	350 - 600 kHz
Range 2	1 - 2 MHz
Range 3	3 - 6 MHz
Range 4	6 - 14 MHz

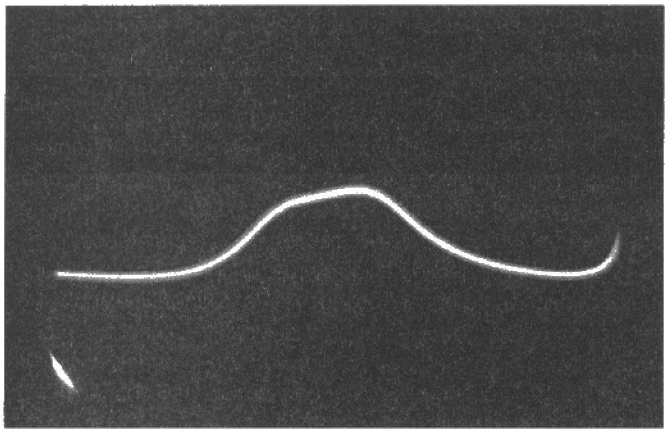
The above tuning ranges can be varied, within reasonably wide limits, by adjusting the inductor cores. Note that with L1, L2 and L3, inductance increases, and frequency lowers, as the cores are driven down. The core of L4 has to be set flush with the top of the can for maximum inductance.

Connecting the timebase input increases the reverse bias on the varicap diode and, for a given setting of the tuning control, makes the frequency of oscillation increase. In practice, the unit should produce linear displays of IF systems centred at up to 15 or 16 MHz.

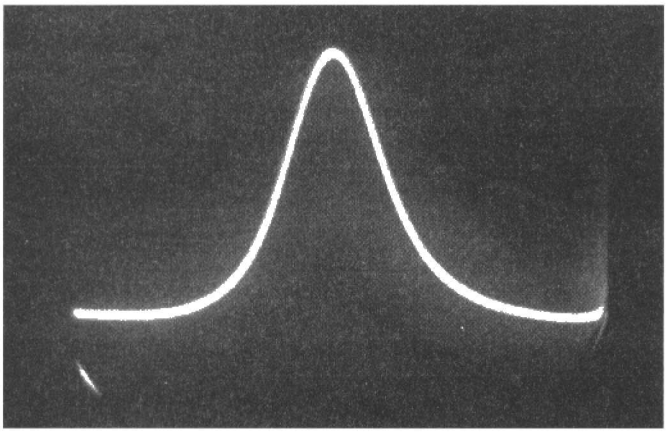
Using the Wobbulator

The connections between the wobbulator, oscilloscope and receiver under test were shown in figure 1. Keep the wobbulator close to the receiver so that the signal injection lead can be as short as possible. The connection between the receiver's detector and the 'Y' input of the oscilloscope may have to be screened, but this was not found to be necessary with the equipment used for the initial trials.

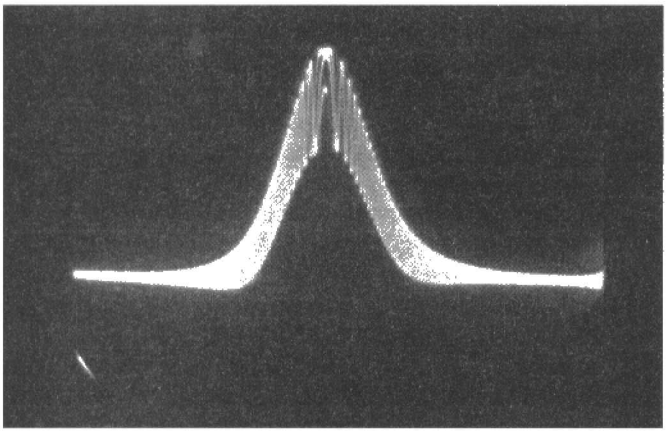
A transistor portable radio can be used for the test and the signal should be injected into the base of the mixer/oscillator transistor. Connect the 'Y' input of the oscilloscope to the audio side of the diode detector. Link the ground terminal on the oscilloscope to the ground terminal on the wobbulator and the ground plane on the receiver. The oscilloscope timebase should be set for the lowest possible sweep rate consistent with an acceptable amount of flicker in the trace. (The display will be distorted, especially when narrow band filters are being checked, if too fast a sweep setting is chosen). The 'X' gain control should be turned well down.



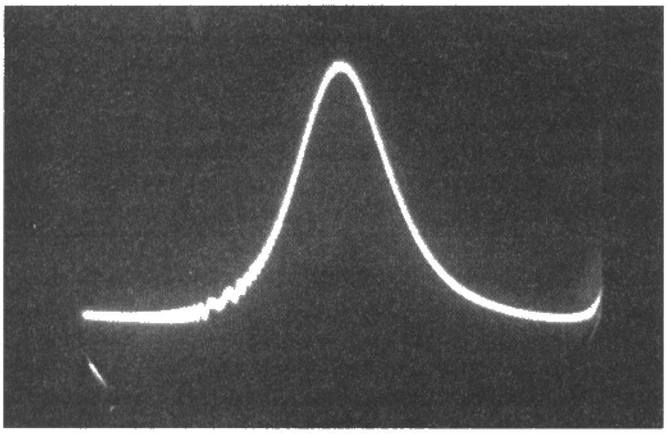
An oscilloscope trace of IF response of a transistor portable radio, before alignment



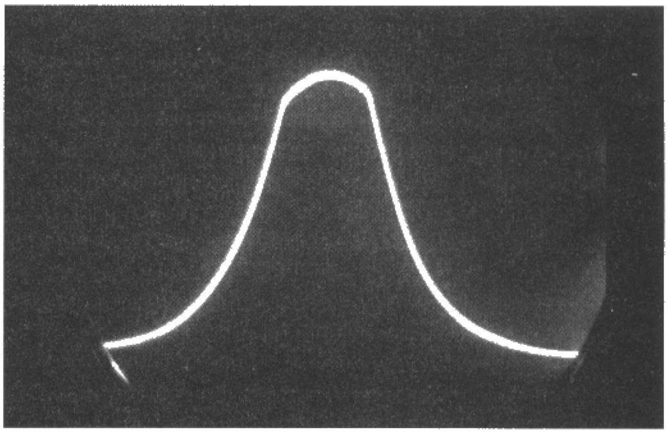
An oscilloscope trace of the same radio, after alignment



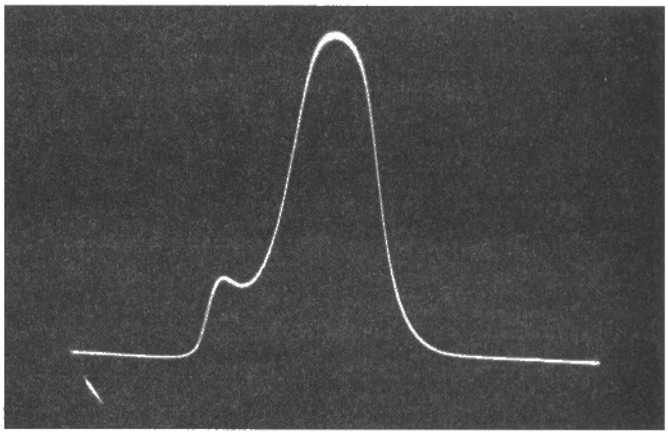
Using a second signal generator to pinpoint frequency along trace: zero beat point at crest of peak and second generator dial reading 460 kHz



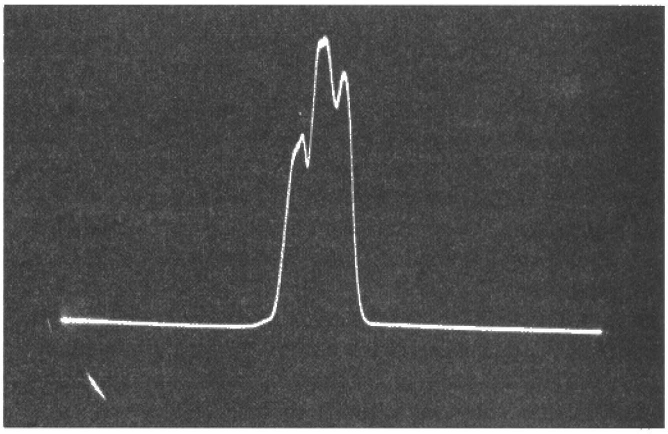
As the previous photo, but with the zero beat point set close to the floor of the trace and the second generator dial reading 470 kHz



Flattening of the trace caused by too high an injection level resulting in receiver overload



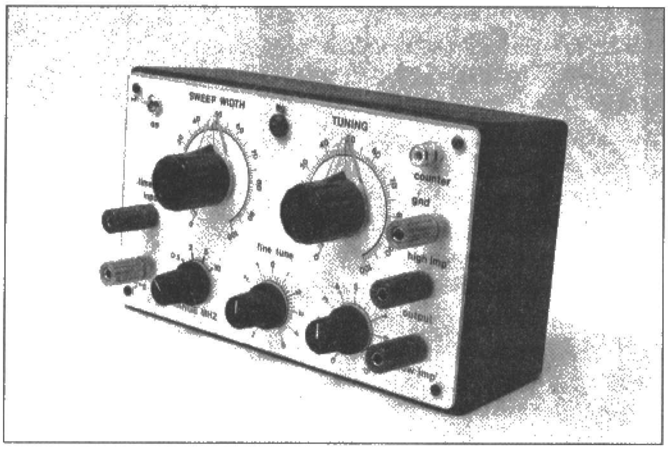
The trace produced by an IF strip comprising four tuned transformers and an inexpensive 4-kHz mechanical filter. Receiver aligned for maximum sensitivity



The trace produced by an IF strip comprising four tuned transformers and a 2.6 kHz ceramic filter. Again, receiver aligned for maximum sensitivity

Switch the wobbulator to the appropriate range (invariably Range 1, or 0.5MHz, for a transistor portable AM radio), set the sweep width control to about half travel and adjust the wobbulator tuning until the receiver's IF response is displayed on the oscilloscope screen. Turn down the signal level (R13) in order to check that the receiver's IF stages are not being driven into clipping: this results in a flattening of the displayed peak, as shown in the photograph of the oscilloscope trace of IF response of a transistor portable radio, before alignment.

The timebase sawtooth voltage does not drop to zero with respect to ground. Increasing the timebase input will drive the wobbulator frequency higher as well as shifting it more, and the tuning control has to be turned back to compensate for



this. Adjustments to the oscilloscope's 'Y' input sensitivity, the 'X' gain control, wobbulator output and sweep width all affect the profile of the display. Turning up the sweep width control will reduce the width of the passband profile because it is occupying a smaller proportion of the frequency range displayed on the screen.

This all sounds rather complicated but, in practice, the unit is very easy to set up and operate.

Most domestic receivers in current production have the detector diode wired to give a negative-going output. This will generate a trough rather than a peak on the screen. The trace is, however, still perfectly useable.

Adjustment of the IF transformer cores will, of course, change the profile of the display. In the case of most domestic receivers, they should be adjusted for the highest peak. Turning up the 'Y' sensitivity and adjusting the other oscilloscope controls until the tip of the peak almost fills the screen enables the cores to be set with extreme accuracy.

Some authorities recommend that the receiver's oscillator stage and AGC network should be disabled in order to avoid any distortion of the trace. However, if the injected signal is kept as low as possible, and if the aerial is disconnected from the receiver (tune portables to a silent part of the dial), no problems should be encountered with spurious responses.

The effectiveness of the simple output attenuation control diminishes as frequency increases, especially when the high impedance feed is used, and it may be necessary to place the signal lead close to the injection point, rather than make a direct connection, in order to keep amplitude sufficiently low.

Some of the traces likely to be encountered are shown in the trace photographs.

Measuring the IF bandwidth

Constructors involved in experimental work with radio receivers will wish to determine the frequency at the crest of the peak and at various attenuation points down the skirt. To do this, place the output lead from another signal generator close to the output terminal of the wobbulator. The second generator must be tuned to the receiver's IF, its output turned well down, and modulation switched off. The trace on the oscilloscope will become fuzzy and broader. If the frequency of the second generator is now swept slowly across the IF passband, a gap or notch will move along the broader trace. This represents the zero-beat position, where the frequency of the second generator precisely coincides with the frequency displayed on the trace. The notch will be shallow at the bottom of the skirts, where receiver sensitivity is low, and deep at the crest of the peak, where receiver sensitivity is at its greatest.

Multiple conversion receivers

Additional equipment is needed to investigate the response of front-end IF filters in multiple conversion receivers, as they do not feed directly into the detector and signal levels can be too low to produce a display on the oscilloscope. A suitable RF probe unit, which amplifies and detects the signal, will be described in a subsequent issue of ETI.

PARTS LIST *for the Wobbulator*

Resistors

Fixed resistors are 5 percent tolerance, 0.25 watt

R1, R4	22k linear pot
R2, R14	4k7
R3	1k linear pot
R5	33k
R6	1M preset horiz pot
R7, R8	100k
R9, R11	1M
R10, R12	100R
R13	4k7 linear pot

Capacitors

All ceramic unless otherwise stated.
All 25V working or greater.

C1, C6, C9	100nF
C2, C3, C8, C11	10nF
C4	1nF
C5	1uF tantalum
C7	220pF
C10	3p3

Inductors

All by Toko

L1	RWO6A7752EK (green core)
L2	154FN8A6438EK (violet/deep red core)
L3	154FN8A6439EK (yellow core)
L4	KXNK3767EK (pink core)

Semiconductors

IC1	78L12 (12V regulator, rated 100mA)
Q1, Q2	2N3819
D1	KV1235 or KV1236 (varicap diode, see text)
D2	1N4148
D3	2mA LED

The Toko coils, varicap diode and 2mA LED can be obtained from Cirkit Distribution, Ltd., Park Lane, Broxbourne, Herts. EN10 7NQ. Tel: 01992 448899.

Switches

SW1	2-pole 6-way, Lorlin plastic cased rotary switch.
SW2	Single-pole single-throw toggle switch.

Miscellaneous

Materials for PCB, Vero pins and hook-up wire. Stand offs for mounting PCB and self-tapping screws. Control knobs, terminals, phono socket for counter, LED holder, battery connectors. Plastic box or other enclosure, materials for front panel and scrap aluminium for battery holder.

Regulated Battery PSU

Andrew Armstrong

A tiny, light, and efficient surface mount supply, designed as an alternative power source for the Wobbulator project, but suitable for a wide range of projects. It allows a cheaper and more convenient choice of batteries, as well as making them last longer.

This project is being published this month as an alternative means to power the Wobbulator project elsewhere in this issue, but it is suitable for use with most battery powered items. When a supply voltage of, for example, 12V is needed for a project, by far the simplest method to obtain it is to use two 9V batteries in series, and then use a 12V regulator to provide the correct voltage.

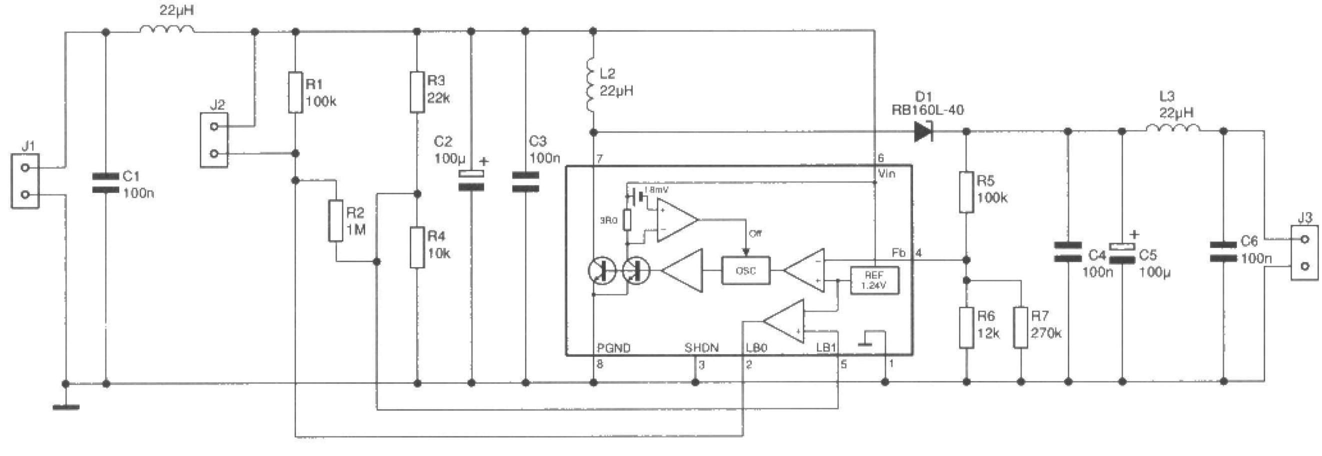
If the current consumption is very low, or if the use of the equipment is to be very intermittent, then this approach is probably the best one. However, if the power consumption and type of use is such as to run down the batteries fairly rapidly, then there are other solutions.

An alkaline PP3 sized battery contains a nominal energy of 4.95 watt hours and costs around £3.50, while AA cells cost around £3.60 for four, with a total of 16.2 watt hours nominal energy content. If disposable batteries are used, these are certainly more economical, but to use eight of them to obtain 12V might be inconvenient, moreso if the 12V needs to be regulated. In that case, about a dozen would be needed to allow for an adequate voltage to run the regulator when the cells are partially run down.

This project solves the problem in a different way. A smaller number of AA cells are needed, giving a lower voltage than that which is finally necessary. Then a switched mode supply is used to increase the voltage to a suitable level. Switched mode power supplies always waste some power, so that part of the energy stored in the battery will be lost, but even at the most pessimistic estimate the cost of battery power using this approach and AA cells will be less than half that using PP3 batteries.

In addition, of course, the switched mode supply can provide a well-regulated output until the batteries are much flatter than would be possible without the switched mode supply. If a regulated voltage is needed, then the PP3 approach probably has lower efficiency over most of the battery's life, because of the loss inherent in feeding 18V into a voltage regulator to get 12V out. In this case the three to one advantage will be maintained or enhanced by using the switched mode solution.

Figure 1: The circuit diagram of the pcb



The design

The circuit diagram of this power supply is shown in **figure 1**. It uses an LT1303CS8 switched mode supply chip. All the components for this design are available from Electromail.

In order to make it small and light, this project uses surface mount components. As a result it is 56mm x 36mm, with a maximum thickness of 6.5mm. It is designed to fit on the back of an AA battery pack. It is not much wider than a 2-cell pack, and is completely covered by a 4-cell rectangular pack.

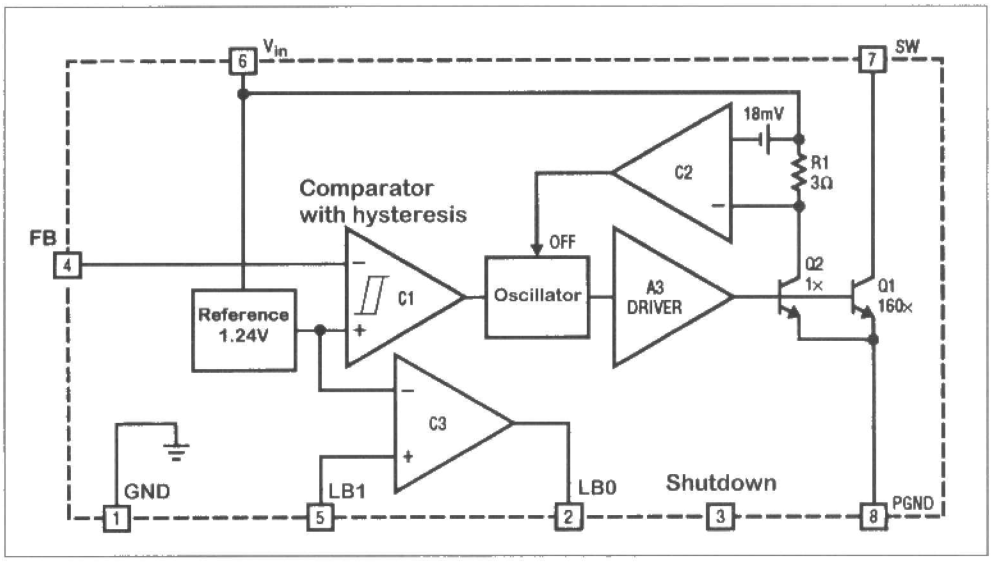


Figure 2: block diagram illustrating the functioning of the LT1303

Switched mode power supplies, left to themselves, generate interference which is both radiated, and conducted along the input and output wires. This design incorporates filters which minimise this effect, and a circuit board layout which keeps the radiating tracks as small as possible.

Starting at the input, C1 and L1 form a filter which attenuates any interference getting out via the input connection. The prototype had too low a noise level on the input to be detectable on an oscilloscope with a maximum sensitivity of 50mV/cm.

Continuing from the input, the next part of the circuit is the low battery warning circuit. This uses the on-chip voltage reference and comparator to switch on a led if the input voltage falls below 3.84V. R3 and R4 set the voltage, and R2 adds a small amount of hysteresis.

C2 and C3 are there to minimise the supply ripple as the chip switches. The 100uF capacitor must be a low esr (equivalent series resistance) type, because of the high ripple current flowing. In addition, a ceramic capacitor is added to increase the decoupling at high frequencies, specifically to minimise switching spikes on the input voltage.

At this point is is worth noting that when the switching transistors in IC1 switch on, there is a current spike caused by the capacitance of D1 and the stray capacitance of L2. Of the two, the capacitance of D1 is much greater. Part of the reason to need low esr capacitors and a ground plane is to minimise the interference which actually gets out of the unit. The losses caused by diode capacitance can form a significant part of the overall circuit loss if the choice of diode is not ideal. It is important to have a diode with a low enough voltage drop at its operating current not to dissipate too much power in resistive losses in the diode. However the lower the ON resistance of the schottky diode, the higher its capacitance, and all the energy stored in the capacitance of the diode will be lost at the time of switching.

There does exist a much more complicated power supply topology which can recover some of its energy, but it is not appropriate at these power levels.

The output storage capacitors C4 and C5 are more critical than the input capacitors in keeping the level of interference right down. On the input capacitors, the current drawn is typically continuous with triangular ripple at the switching frequency. However, the current supplied to the output capacitors by D1 is in discontinuous pulses with a sharp rising edge. Also, the current required to charge the capacitance of D1 when the switching transistors turn on must flow through the output capacitors, and this current is only limited by the resistance of the circuit and the maximum current capability of the switching transistors. If standard rather than low esr capacitors are substituted for C2 and C5, then the circuit is unlikely to work very well.

The output voltage of the circuit is set by its internal voltage reference and by the potential divider resistors from the output voltage. An extra resistor, R7, has been added to the circuit after the first prototype (on the photographed PCB) was made. This has been added to permit finer adjustment of the output voltage. For example, it was only possible to set the output to 11.3V rather than the preferred voltage of 12 volts using just two resistors from the E12 series. (E24 series resistors are not so widely available in 0805 surface mount packages.)

The LT1303

This dc-dc converter ic has particular virtues which suit this type of application. First of all, its quiescent current (that is, with input connected but no load) is 120uA. Secondly, its switching transistors have a typical voltage drop of only 170mV at 1A. This is particularly important at low input voltages. With 2V input, 170mV represents a loss of 8.5 percent.

This is undoubtedly a compromise, in that a lower saturation voltage could have been obtained only at the expense of a higher operating current, which would waste more power than would a drop of 170mV.

Operation of the LTI303 is best understood by referring to the block diagram shown in **figure 2**. When C1's negative input, related to the output voltage by the appropriate resistor-divider ratio, is higher than the I.24V reference voltage, C1 (comparator I)'s output is low. C2, A3 and the oscillator are turned off, drawing no current.Only the reference and Cl consume current, typically 140uA.

When comparator 1's negative input drops below I.24V and overcomes the 6mV hysteresis, C1's output goes high, enabling the oscillator, current comparator (C2) and

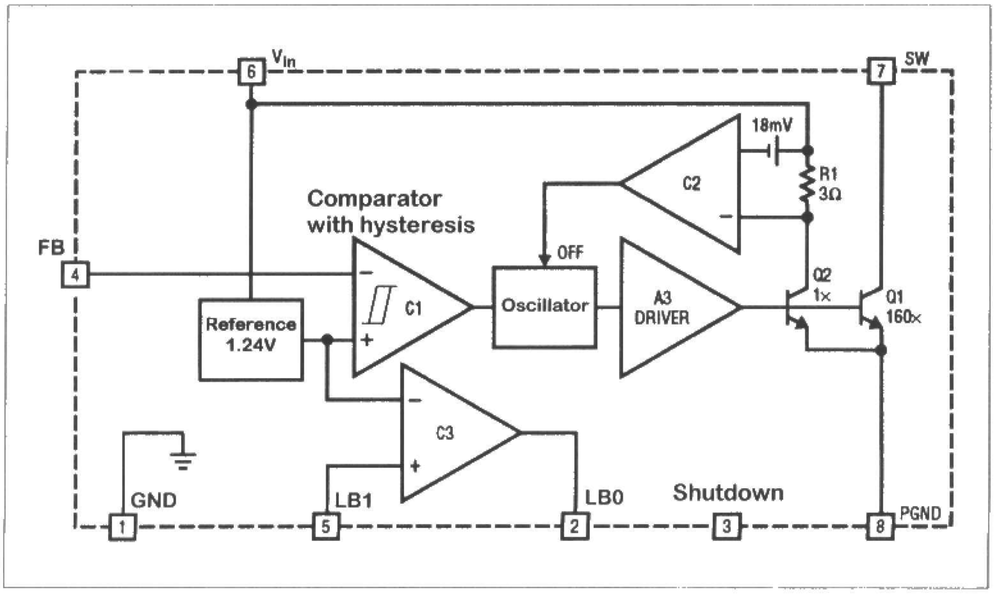


Figure 3: the switching waveform, and the ripple on the output. This is shown with the oscilloscope on AC coupled, and shows the reduction of voltage when the switching stops briefly

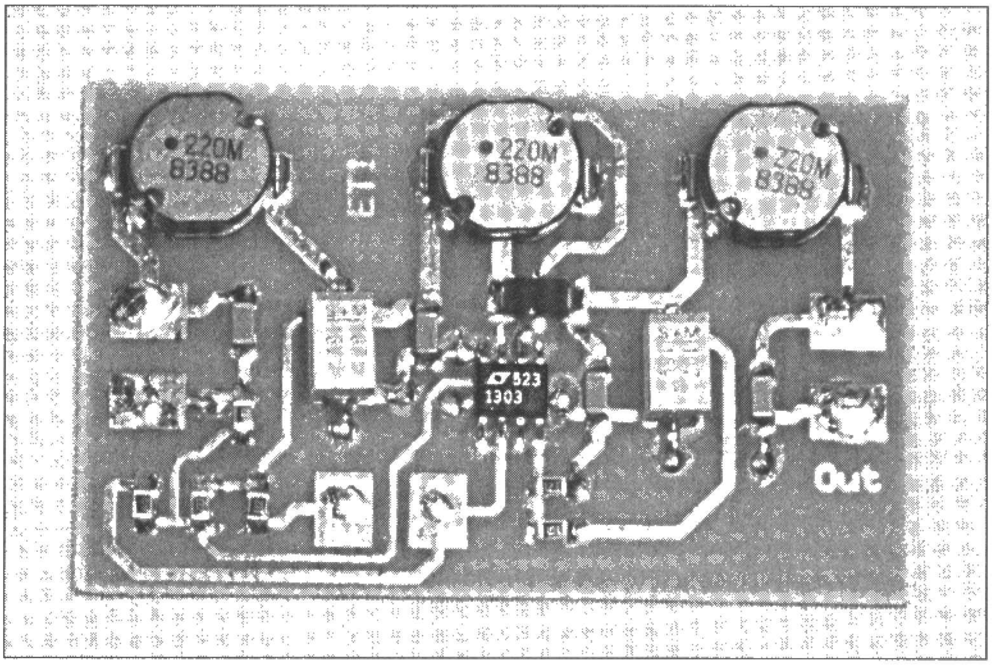
driver A3. Quiescent current increases to 2mA as the device goes into active switching mode. Q1 then turns on in controlled saturation for nominally 6us or until current comparator 2 trips, whichever comes first. The switch then turns off for approximately 1.5us, then turns on again.

The LT1303's switching causes current to alternately build up in the inductor (L2 on the schematic) and feed into output capacitor C4 in parallel with C5 via DI, increasing the output voltage. When the output is high enough to cause comparator 1 output to go high, switching action ceases. The output capacitors supply current to the load until the output voltage decreases enough to force the output of comparator 1 high, and the entire cycle repeats. **Figure 3** illustrates the effect of this on the output voltage.

The extra filtering in this circuit makes the ripple almost sinusoidal, although there is significant harmonic energy present on the top of C4 and C5. It also makes it possible to reduce the output ripple more than would otherwise be possible. Here is the reason: The hysteresis of the first comparator guarantees that there will be a ripple of 6mV at the feedback pin, at the lower, burst frequency. This translates to around 60mV on the 12V output.

However, if extremely low output ripple is needed, the inductance of L3 can be increased (at the expense of slightly increased I2R loss due to its higher resistance), and an electrolytic capacitor in the circuit powered by this supply can then reduce the ripple to extremely low levels while permitting the necessary ripple on C4 and C5.

If switch current reaches 1A, causing 02 to trip, switch on-time is reduced and off-time increases slightly. This allows continuous operation during bursts. Comparator 2 monitors the voltage across



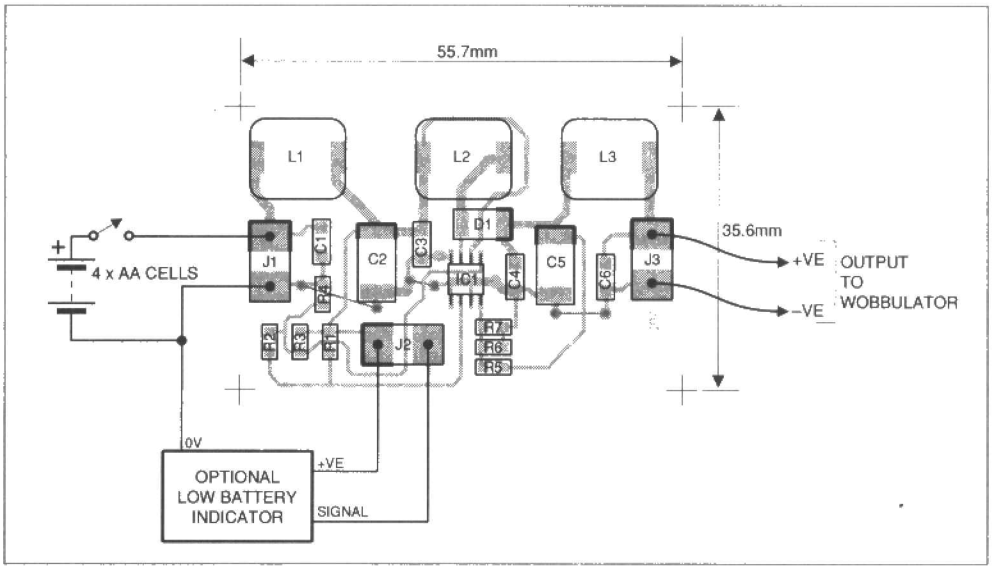


Figure 4: PCB component placement diagram.

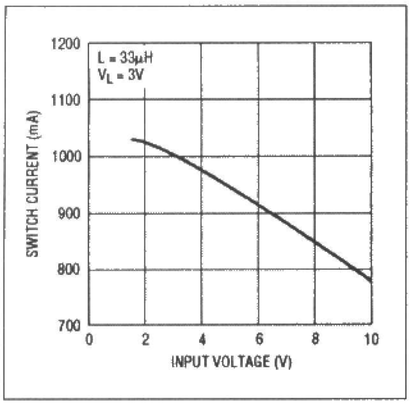


Figure 5: Typical switching current limit plotted against voltage supply

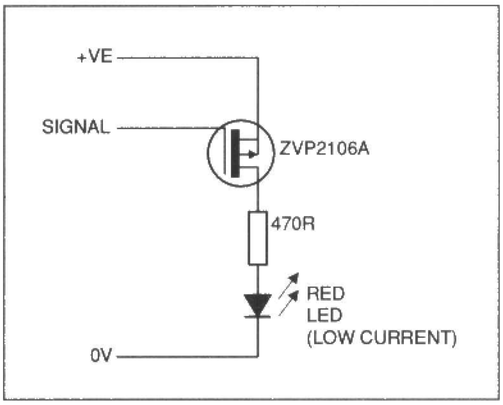


Figure 6: optional low battery voltage led warning indicator

3R resistor which is directly related to the switch current. Q2's collector current is set by the emitter-area ratio to 0.6 percent of Q1's collector current.

When R1's voltage drop exceeds 18mV, corresponding to IA switch current, comparator 2's output goes high, truncating the on time portion of the oscillator cycle and increasing off-time. This method of measuring an accurate proportion of the total current is only possible if the two transistors are made on the same substrate, so this sort of technique is not possible with separate discrete semiconductors. Note, however, that power mosfets with two source connections, one passing most of the current and one passing a small proportion, are made for this sort of use.

Assembly

The component layout and wiring is shown in **figure 4**. This circuit has all connection except for some of the ground tracks on the top side. It is intended that a ground plane be used on the underside to maximise the efficiency and minimise radiated interference. Before fitting any components, the eight circular pads with holes in them should be linked to the groundplane using thin tinned copper wire.

If only a single sided pcb is available, then a good substitute is to use a piece of self-adhesive copper tape, or failing that a thick piece of tinned copper wire on the underside of the pcb, then use the thinner tinned copper wire to link this to the ground pads.

There is more than one approach to surface mount assembly by hand. Some people advocate the use of solder paste. To use this, you apply paste to the pads, then position the components, The paste is sticky enough to hold the components in place, and they can be soldered using a hot air gun or a small soldering iron. In this latter case each component may need to be held down while being soldered. Otherwise there is a risk, particularly with the smaller components, that the surface tension of the molten solder may make them stand upright, prohibiting soldering to the other pad(s). This is commonly referred to as "tombstoning".

I have always found that approach messy, and would recommend instead that one pad from each component footprint has a small blob of solder attached to it, applying heat for the minimum time necessary to achieve this so as not to burn away all the flux. Then pick up the component with a small pair of tweezers, and hold it in place while re-melting the solder on to the pad. It should be possible to produce a neat and reliable solder joint, with the component positioned correctly. Then the other connection(s) can be soldered in the normal manner.

If the first solder joint does not turn out well, it is simple to remove the solder from the pad with a piece of solder wick, or a miniature solder sucker, and make a new and better joint.

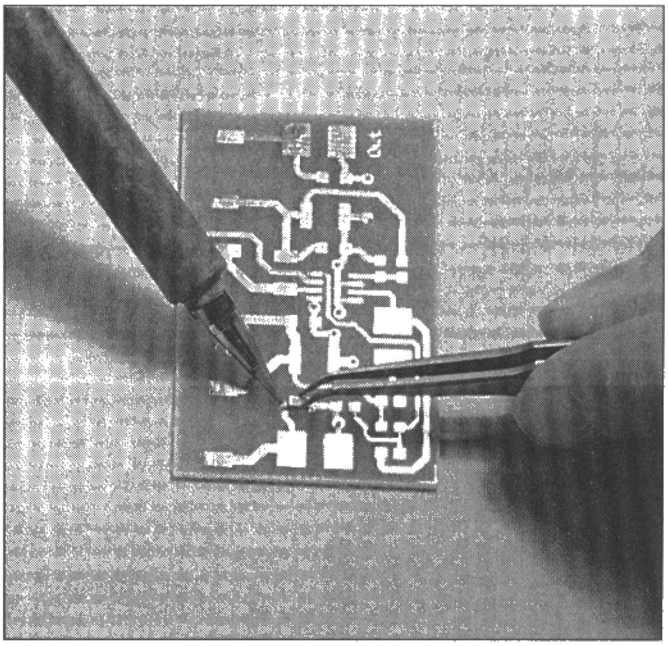
The best solder to use for the purpose is the special grade for surface mount. This is very fine gauge, and contains a tiny proportion of silver to lower the melting point below that of ordinary solder. However, ordinary solder of a fine gauge can be used successfully, with just a little more care.

Applications

The component values used here are chosen to give a 12V output from a four-cell pack of AA cells. The circuit is suitable for a range of input and output voltages, with the change of several component values. Indeed, other projects currently at the planning stage may use this circuit as the power source.

The maximum output voltage available without damage to the ic is 25V, though prudence might dictate never exceeding 24V. The maximum input voltage is 10V, while the ic is guaranteed to operate at 1.8V. When used to convert battery supplies, between two and six alkaline cells in series may be used as the power source. If nickel cadmium cells are used, three to seven in series would be appropriate. Four cells in series gives a good supply for most purposes, whether alkaline or nickel cadmium cells are used.

The output power is limited primarily by the current limit of the switching transistors, and the input voltage. To take a simple example, if the switch limits the average input current to 500mA, and the input voltage is 6V, then the maximum output power is 6V x 0.5A = 3W, less the losses in the circuit, giving around 2.5 watts output.



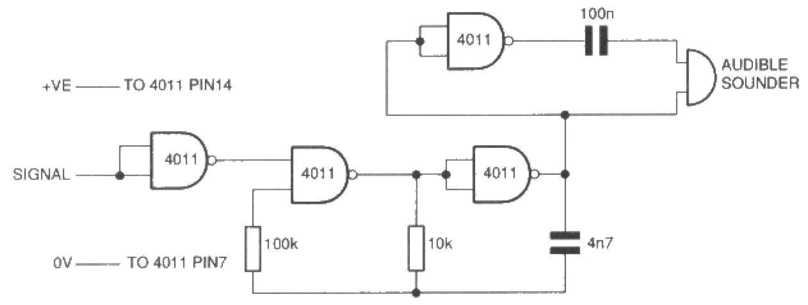


Figure 7: optional audible low battery warning circuit

The graph of typical switching transistors current limit against input voltage is shown in figure 5. This is the peak current limit, so that the average will be somewhat lower. If the average current is only 10 percent lower than the peak, then at an input voltage of 2V, the theoretical maximum input power would be 1.836W. In practice, it would probably be reasonable to expect over a watt of output at a moderate voltage stepup, and less at a higher output voltage.

The reason that the output power would be lower at a higher output voltage is that, while the switch is off and the inductor is delivering power to the load, its current will decline more rapidly if the load voltage is higher. This will increase the ripple current, thus lowering the average current and hence lowering the input power.

On equipment which is dual powered, battery or mains adaptor powered, this circuit can be very useful. So long as the mains adapter supplies enough power to make the unit work at sufficient voltage for the power throughput demanded, and does not exceed the required output voltage, then an unregulated supply can be used for equipment needing to run from a regulated voltage.

Table 1 shows component values and suggested battery configurations for a range of voltages up to 15V. If higher output voltages are needed, then C5 must be replaced with a component having a higher voltage rating.

Nominal Voltage	R5	R6	R7
15V	100k	10k	100k
12V	100k	12k	270k
9V	47k	8.2k	82k
6V	39k	10k	N/A
5V	47k	18k	100k

Table 1: resistor values for different output voltages

There is a low battery output on this unit. It would be suitable for use as a warning input to a microprocessor, to give adequate warning of power failure. In this application, it might be necessary to increase the value of R1 and use an external pullup resistor to the microprocessor supply. If this power supply were powering a 5V microprocessor or microcontroller, then it would probably be running from only two AA cells, the output voltage of which would be insufficient to reach a reliable logic 1.

The output pin of the ic cannot sink enough current to run a light emitting diode, so the circuit of **figure 6** may be used externally to drive a low current warning led if one is required. If an audible warning is needed, the circuit of **figure 7** will be suitable.

The prototype pcb was tested, and the following figures were measured:

	Input	Output
V	5.94	11.32
I	245mA	111.9mA
Watts	1.455	1.267

This gives an efficiency of 87 percent.

PARTS LIST *for the Regulated PSU*

Resistors: all 0805 5% unless otherwise stated

R1, R5	100k (Electromail 137-449)
R2	1M (Electromail 137-562)
R3	22k (Electromail 137-360)
R4	10k (Electromail 137-326)
R6	12k (Electromail 137-332)
R7	270k (Electromail 137-499)

Capacitors

C1, C3, C4, C6	100nF 1206 case, X7R dielectric (Electromail 264-4179 or 211-3401)
C2, C5	100uF low ESR tantalum X-case capacitor (Electromail 238-9210)

Semiconductors

D1	RB160L-40 Schottky diode (Electromail 263-6869)
IC1	LT1303CS8 dc-dc converter ic (Electromail 197-1874)

Miscellaneous

L1, L2, L3	22uH inductors (Electromail 278-7917)

Battery holder for 4 AA cells (e.g. Electromail 494-628)

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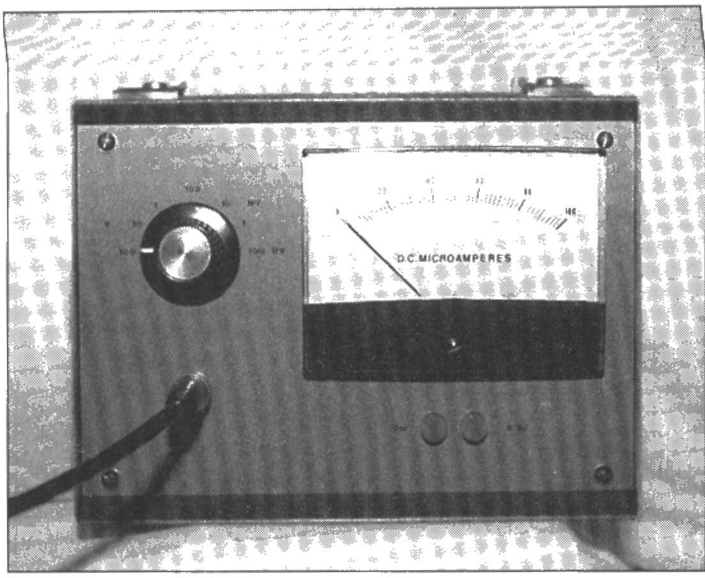


Audio Millivolt Meter

An audio millivoltmeter is designed to read AC signals accurately over the audio range. This six-range millivolt meter also reads up to 50kHz.

Tony Sercombe

A millivolt meter is a useful piece of equipment to have in the workroom, particularly if you are dealing with very low levels of AC at audio frequencies and above. Such instruments are expensive and may be hard to justify in many cases. Commercial meters also have some facilities that you may not require very often. An alternative is to construct your own. If some limitations in terms of ultra precise accuracy and the number of facilities are accepted, a useful instrument can be constructed, that with care should give yóu years of service.

Description

As will be seen in **figure 1**, the circuit consists of an fairly wide band amplifier, preceded by a high impedance buffer, followed by a full wave bridge rectifier, and powered by the usual split supply.

The prototype has six ranges from 1 millivolt to 100 volts, in step multiples of x10. The response is flat to 50kHz, the limit of the test generator, and the input impedance is almost 20M. There is a separate on/off switch and battery test switch. The signal to be measured is fed via a 56n capacitor to the top of the resistor chain. The signal is tapped off at six points on the divider chain by the wiper of the range selector switch, The first ic stage uses a TLO7I which is connected as a high impedance buffer amplifier, which has unity voltage gain. However, the input impedance of this stage is very high and is quoted as 1 tera-ohm, or one million megohms. The total resistance of the chain is I9.99M. This resistance in parallel with the input gives, for practical purposes, the same 19.99 megohms input resistance. If 1 percent tolerance resistors are used for the chain, then the total tolerance will be within 1 percent. The resistors I have used throughout the circuit are from the Maplin High Stability 0.6W range.

The next part of the circuit is an amplifier with a gain of 40 dB, or x100. In fact, the gain is x101, which is the result of working out R1+R2/RI. It uses the CA3130 ic. This is required to obtain sufficient bandwidth at this gain. The ic is not compensated, and in some examples of the circuit it may need a compensation capacitor between pins 1 and 8. In the prototype a 2.2p capacitor was fitted, and as previously stated the response was flat to 50kHz. This may perhaps be regarded as optional, and in the prototype was fitted under the board, directly to the pins of the ic socket, to minimise lead length. The stage has basic supply decoupling.

The final ic is a TL071, also connected in the non-inverting mode. It has pre-set variable gain to adjust the calibration, and drives a full wave bridge rectifier, which, together with two protection diodes, feeds the meter. Offset nulling is required here, and is provided by the preset control RV2. This stage has basic supply decoupling also.

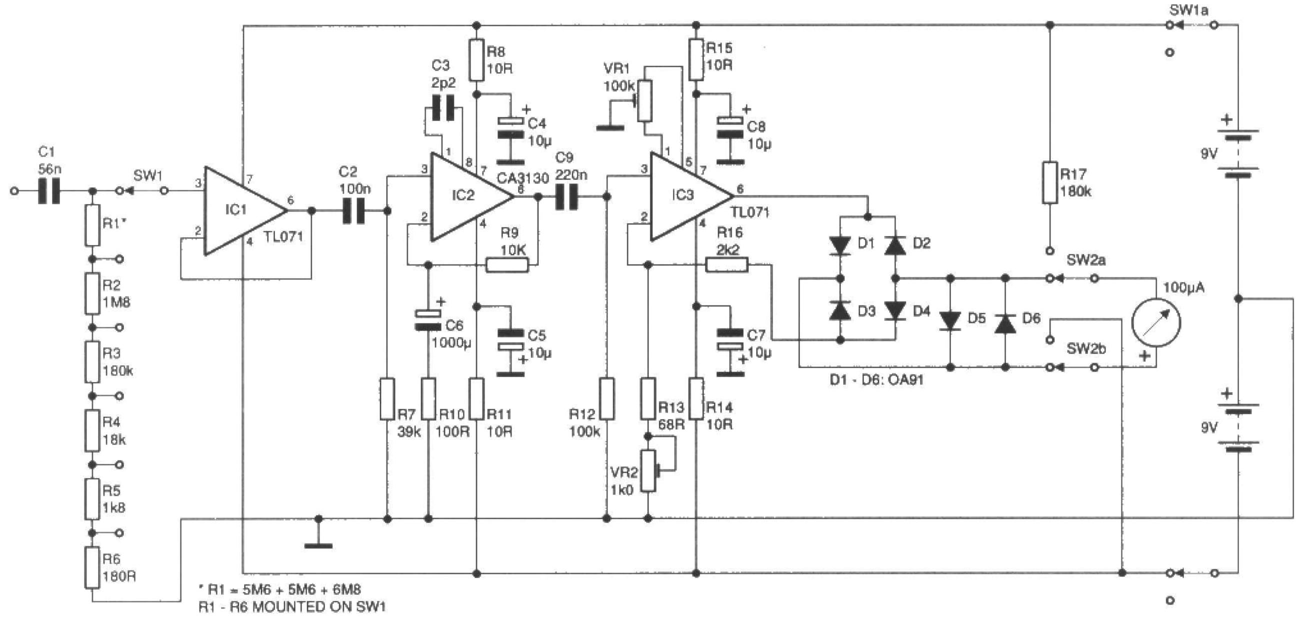
A metal case must be used to house the meter, otherwise extraneous electrical noise will severely interfere with readings. For the same reason, the switch needed separate screening in the prototype. Because of this sensitivity to electrical interference, a mains supply unit was not considered. Generally a supply of this type is more economical in the long term than battery power. However the problems encountered in this case would be very considerable, as the best of transformers must leak some flux, and this alone would be enough to upset readings, and it is not envisaged the unit will be left switched on for long periods anyway. If required, a self-contained 3mm flashing led could be fitted to the front panel to give a visual indication of ON status, while going some way to conserving power. However it should be well decoupled close to the panel, and supplied from the total battery voltage using the appropriate value of decoupling resistor.

Construction

The component layout is shown in **figure 2**. Once the passive components and ic sockets have been fitted to the board, it should be checked for any mistakes in soldering, track breaks etc. The ics may now be inserted into their sockets. Do not use anything made of metal to insert IC2. A piece of card or plastic or even a thumbnail is best for this.

It will be easiest to assemble the front panel parts first. Drill

Figure 1: the circuit of the Millivolt Meter



and fit the meter movement, the switches and BNC socket first of all. The switch assembly must now be made. The input resistors are mounted on the switch by their leads, and are small and light enough to be self-supporting. A 12-way switch is used, and stopped off at 6 ways; the spare tags may be used to support the resistors where more than two are fitted between ranges. Keep them in an upright position as far as possible.

Next, you need to make a screening sleeve. Most model shops sell tin or brass sheet in thicknesses of a few thousandths of an inch. This may be turned into a sleeve and spot soldered three or four times along the seam. A piece of paper or plastic sheet can be used as a lining to prevent shorts, and the top bent over and soldered. When the switch is fixed to the front panel and the 56n capacitor wired from the BNC socket and the screened input cable attached, the sleeve may be pushed over the assembly and spot glued at its bottom edge with epoxy resin. Take care that the resistor wiring is correct before fitting the sleeve. Next, put the PCB in its intended case so that the track is close to the metal floor, and wire up the rest of the connections. At this point a tag should be fitted somewhere close by, and all separate pieces of the case wired to it, including the zero volt track on the PCB. The BNC earth return and front panel can share the input cable screen. Do not fix the PCB down permanently just yet, in case a 2.2p capacitor needs to be fitted to 1C2

Calibration and use

When all external connections have been checked, power may be applied. Firstly, set the range selector to 100V. Put a temporary short across the input of 1C2 to ground. Next, put the meter in its intended operating position and check that the pointer is at zero. If not, adjust carefully with the set-screw on the front panel. Switch on and note the meter movement. In all probability the pointer will swing hard over to the end stop. In any event it will leave the zero mark. This is corrected by adjustment of the offset null via RV2. An insulated trimming tool should be used for this. It will be found that precise adjustment is a little tricky, and once the approximate point has been reached, a very small movement is all that is needed to bring the pointer to zero once more.

Switch off and remove the short. An input signal of about

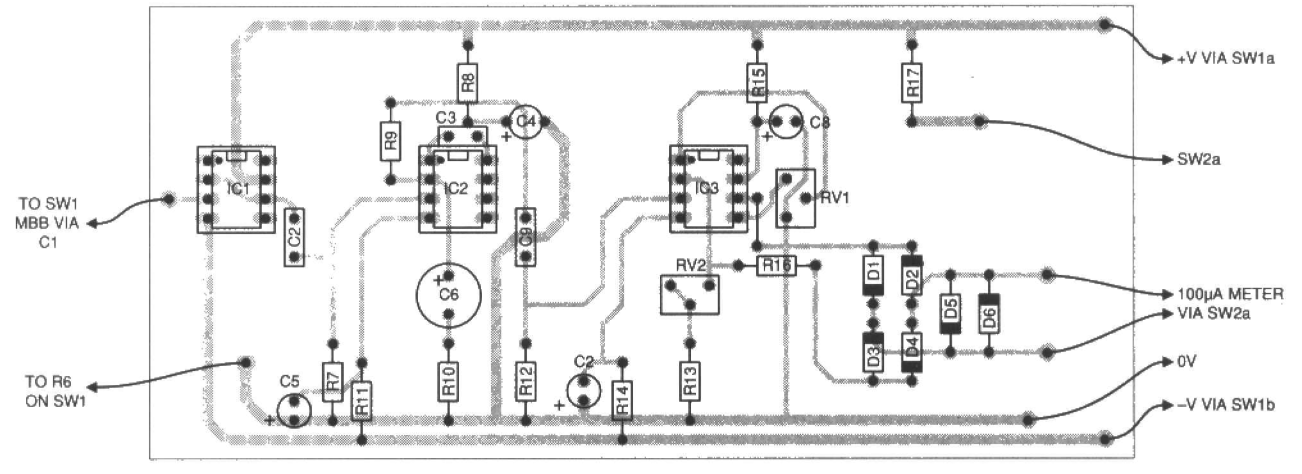
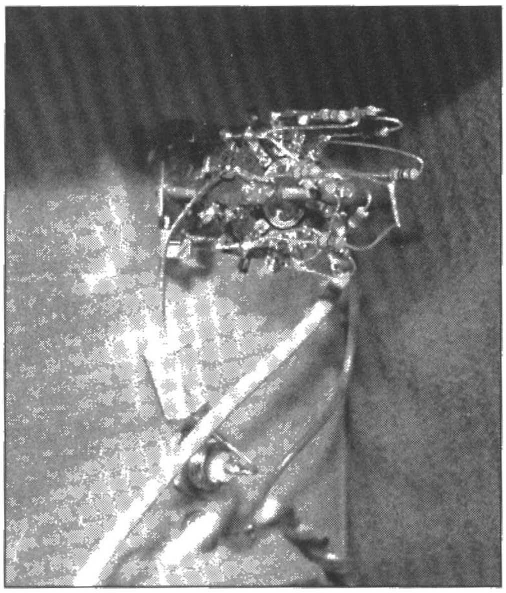
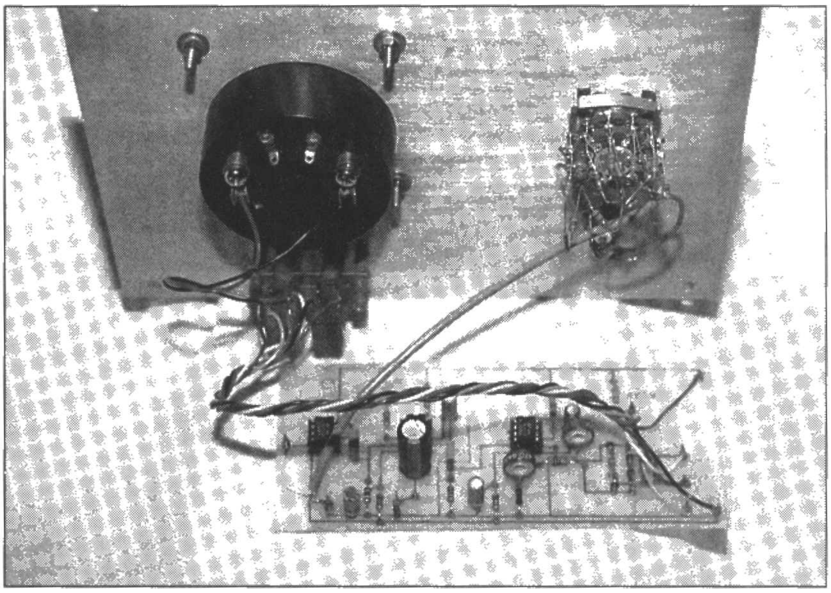


Figure 2: the component layout of the Millivolt Meter



The resistor assembly on SW2



The board wired up to the front panel furniture

1kHz needs to be applied at somewhere near the maximum level of one of the ranges. This will then take into account the 2-3 percent accuracy of the meter. This degree of accuracy is usual for analogue meters. A signal generator is ideal for this purpose, and another meter is also required. If these are unavailable, perhaps a local technical college or a colleague may be able to help.

Set a voltage up, say 9 volts on the reference meter, and carefully adjust RVI to obtain the same reading. The above procedure may be repeated to get the best accuracy. When set, the presets can be locked with a drop of paint if the construction of the preset permits this.

If the meter should exhibit any unexpected movements, or swing over to maximum on some ranges, the 2.2p capacitor should be connected directly to the pins of the socket, under the PCB. Do not use a capacitance of much more than this, as it will curtail the high frequency performance. The case can now be fully assembled. It will be noticed that when the assembly is complete. If the crocodile clips at the end of the test lead are left floating, arbitrary readings will be seen on the more sensitive ranges. This is normal for such a high impedance and sensitivity, and is simply electromagnetic noise. In use, this will be masked by the voltage being measured. When measuring an unknown voltage always start with the range switch set to the 100 volt range, and decrease as necessary. Although the movement is diode-protected, and in fact will stand a fair degree of overload for short periods, this should not be relied upon totally. As a final point, the battery test switch should give a reading of almost full scale with fresh batteries. When this has fallen to 60 on the scale, both batteries should be replaced. A red line or mark could be drawn on the scale to mark this point, but great care would be needed so as not to cause damage to the movement.

PARTS LIST *for the Millivolt Meter*

Resistors

All resistors Maplin "M" range

R1	5M6+5M6+6M8
R2	1M8
R3	180k
R4	18k
R5	1k8
R6	180R
R7	39k
R8	10R
R9	10k
RI0	100R
RI1	10R
R12	100k
R13	68R
R14	10R
RI5	10R
R16	2k2
R17	180k
RVI	100k
RV2	1k0

Capacitors

C1	56nf
C2	100nF
C3	2p2 (if required)
C4,C5,C7,C8	10uF
C6	1000uF
C9	220nf

Semiconductors

C2	CA3130
D1-D6	0A91

Miscellaneous

Switches and case to suit. Meter I00uA (Maplin YJ96E). 2 x battery holders 2 (Maplin JK6SV).

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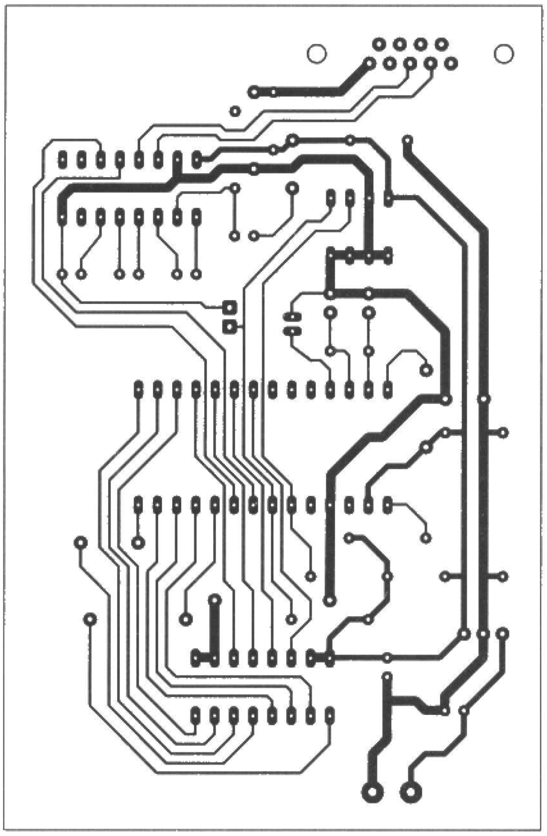
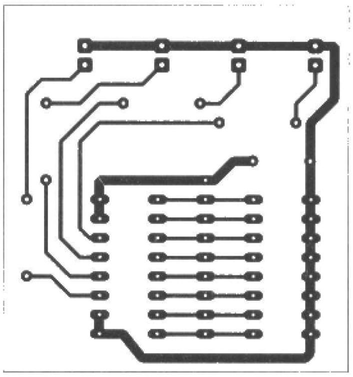
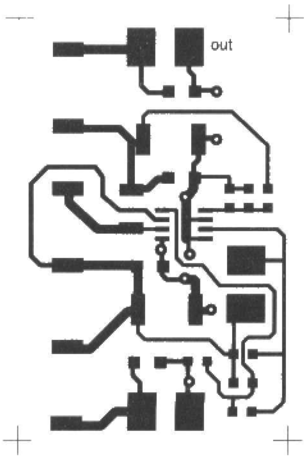


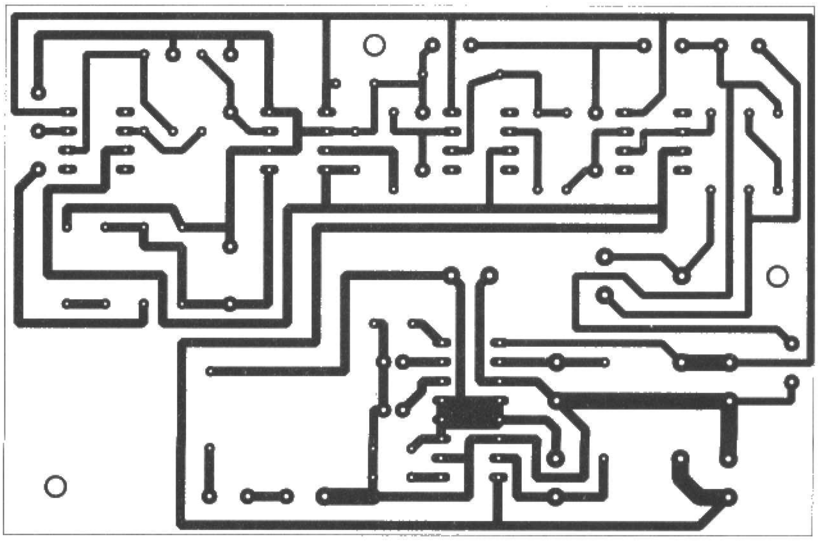
Programmable Logic Microcontoller Board



Programmable Logic Simulator Board



Regulated Battery PSU



Audio Power Meter

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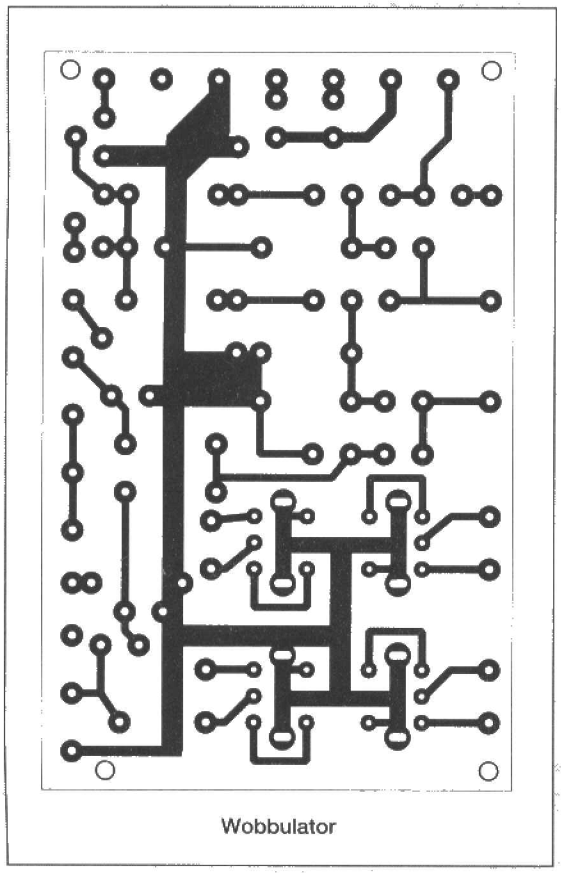
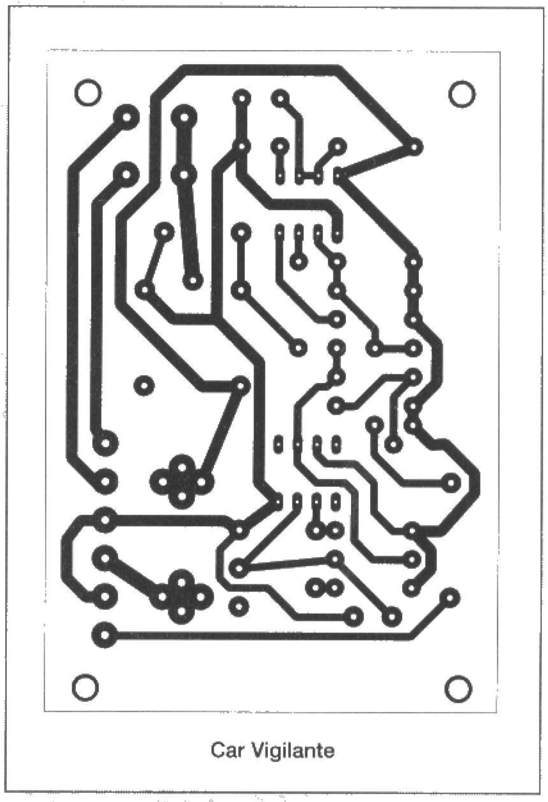
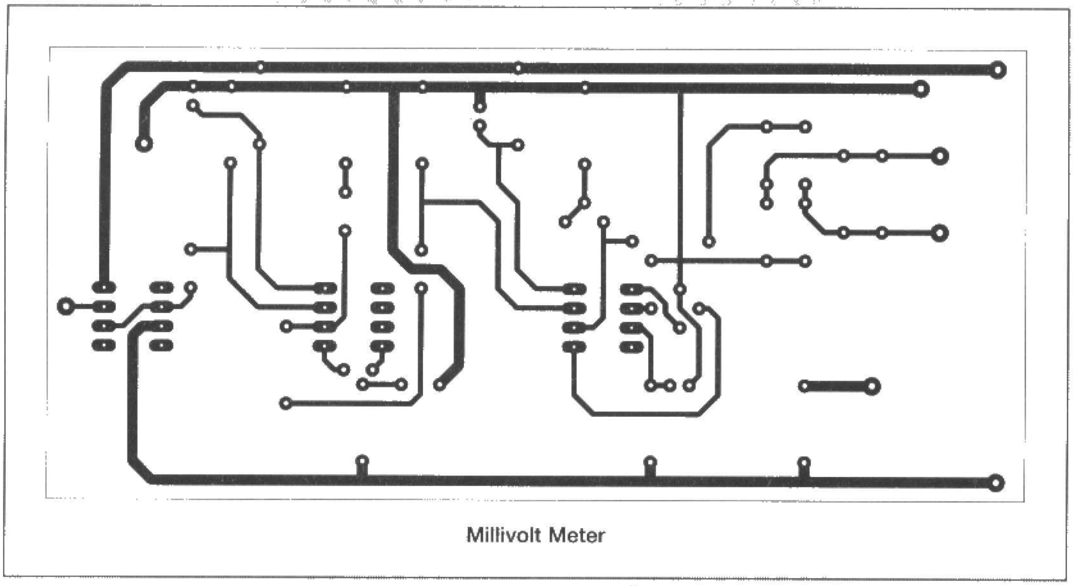

Wobbulator


Car Vigilante


Millivolt Meter

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Only boards listed here are available from our PCB Service. For past issues of magazines, or binders, please see page 74 or contact Readers Services for information.

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You may have a one-off project you would like to share; you may be a regular constructor with a new design you are especially pleased with, or you may be a pro designer trying out ideas and looking for feedback.

Your ideas may be simple or complex, analogue or digital, computer-related or rooted in tradition; elaborately cased or (in some cases) not cased at all.

You may be a private hobbyist, an engineer of advanced standing, or a student. You may be yourself and a soldering iron, a club or a business.

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For further details of authorsí fees and how to write up a project for publication, please write to ETI for our Potted Project Production information sheet. A self-addressed envelope is always a help, but not a necessity.

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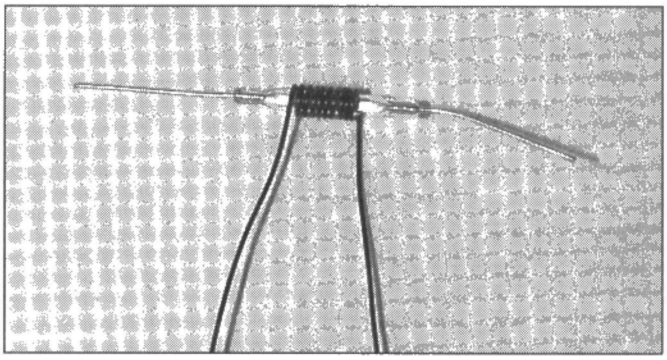
PRACTICALLY SPEAKING

By Terry Balbirnie

Last month in Practically Speaking, I looked at the magnetic reed switch and how it may be made to work using a permanent magnet. This month I shall continue by describing seeing how a reed switch can be operated by an electric current.

All wound up

A reed switch will respond to a magnetic field produced electrically. This may be done by winding a coil of insulated wire around its body and passing a current through it (as shown in the photograph). The effect is the same as if a permanent magnet had been used. Enamelled copper wire is usually used, although the ordinary plastic insulated variety will do for experimental purposes. Note that the sense of magnetisation of the reeds will depend on the direction of the current and the direction in which the turns are wound. For most purposes this does not matter because the reed ends will always take up opposite poles and therefore attract.



A reed switch with a current coil wound around the body. The coil must fit well without cracking the glass case

For the circuit designer, this idea gives a rough and ready way of indicating when current rises above a certain value. It could be used to give an audible warning if a battery was short-circuited, for example. The current needed to close the contacts depends on the pull-in sensitivity of the reed switch and the number of turns on the coil. The sensitivity is expressed in amp-turns (AT) which, for a typical small device, could be some 20 to 50AT. Suppose, for a particular specimen, it is 30AT. This means that one amp flowing through 30 turns will be sufficient to close the contacts. Alternatively, two amps through 15 turns or 100mA through 300 turns, and so on, will have the same effect. Note that the published sensitivity figure (for example, that given in the supplier's catalogue) is for "definite" operation. In practice, the switch will usually work with fewer turns. Making use of this fact is fine when you are constructing a device for one off use. If designing for others, however, such as a project for publication or a device for a client, always stick within the manufacturer's specifications, or you will find that some units do not perform reliably.

Realisation

The circuit shown in **figure 1** is a simple over-current warning device. The buzzer sounds if the current in the circuit being monitored exceeds a certain value. Here, a simple battery and bulb circuit is shown. The approximate number of turns of wire needed for the coil is found by taking the published sensitivity figure and dividing it by the required trip current. Some adjustment to the number of the turns will be needed at the end for the reason above. Note that, where a large current is involved, the wire will need to be of sufficient thickness to prevent overheating.

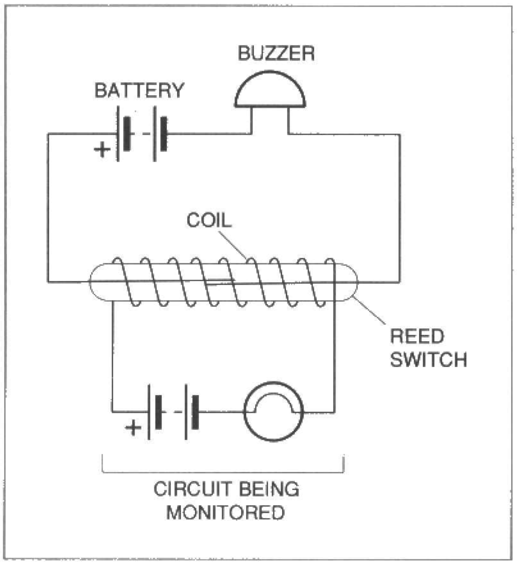


Figure 1: an over-current warning device using a reed switch

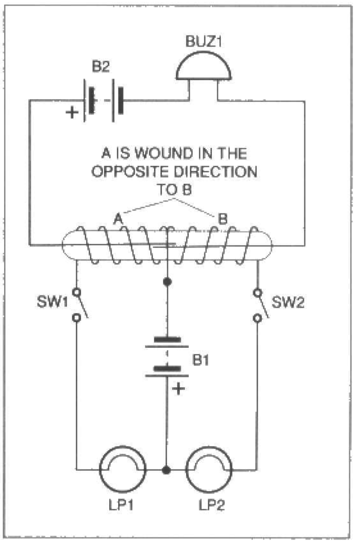


Figure 2: an equal-current indicator. Here two coils are using, with windings in oppsite directions

A further application of the reed switch is as an equal-current indicator (see **figure 2**). Suppose two coils, A and B, having an equal number of turns are wrapped around the reed switch body. The turns in A are wound in the opposite direction to those of B. One connection may be common to both coils A and B (as shown), or they could be completely separate. The number of turns is sufficient to close the reed switch when a certain chosen current flows in either coil.

Look at the positive pole of battery B1. Conventional current flows from here through either lamp LP1 if SW1 is closed, or lamp LP2 if SW2 is closed. Note, however, that the current flows through coil A or B in the opposite direction. With either lamp operating, the reed switch contacts will therefore "make" and buzzer, BUZ1, sounds using its own battery, B2. With both SW1 and SW2 closed, the effect of coil A is to neutralise the magnetic effect of B and the buzzer will remain off. Even if the current in each coil was slightly different, the buzzer would still not sound because the residual magnetic effect would be too little to operate the switch.

This idea could be used, for example, to sense when one of the brake lights on a car was not working. Of course, you could make this circuit operate with unequal currents by adjusting the number of turns on each coil.

Next month, I shall look at encapsulated reed switches and reed relays and how they may be used in simple designs.

Round the Corner

With very rare exceptions, projects for home constructors specify classic through-hole components. However, surface mount technology has become more accessible to us.

In this issue there is a power supply project which uses surface mount components. It has not been made as small as possible, only as small as is needed to fit beneath a set of the batteries intended to run it. Effectively, it makes a 6.5mm-thick layer under the battery holder, and may not even need an increased case size to fit it in.

There are now some components no longer available in through-hole format, although this is not the case with most home construction components. Few lone builders attempt a multilayer PC motherboard with hundreds of hours of design effort given to signal integrity. The fact that the glue-logic chips for the processor are only available in a surface mount package with pins too closely spaced for hand-soldering is unlikely to trouble most of us. However, there are some useful components that are only available in surface mount, and can yet be used by the home constructor.

As described in our feature on surface mount components in Issue 7 this year, passive component sizes are specified by the imperial measurement system. An 0805 size resistor is 0.08 inches by 0.05 inches. In my experience, from the perspective of someone with none too steady hands, and who wears spectacles for very fine work, hand-soldering components sizes down to 0805 is no problem. Down to 0603 is more tricky but still quite practical, and 0402 requires the use of magnifying goggles and lots of coffee and patience.

Now that several suppliers selling to hobbyists stock a good range of surface mount parts, I believe that surface mount projects are practical for most people and an interesting design area to get into. I reckon that the judicious use of surface mount technology will add a new dimension of magic to home construction, with the ability to make very small projects with large functionality.

Another surface mount project is at the planning stage now, and if you the readers like the idea, we can do more. Tell us whether you would like to see more surface mount projects. If you would, we will try to see that surface mount projects make a regular appearance in ETI. Write to us or contact us on our email address eti@aaelectron.co.uk and tell us what your preferences are, and what your experience with surface mount construction (if any) has been so far.

Next Month

Volume 28 No 1 of *Electronics Today International* will be in your newsagents on 1st January 1999 ... Microchips can make a miraculous difference to the health of people with severe disabilities such as blindness. We report ... Pei An and Pinhua Xie describe a PIC-driven analogue data interface for the Psion 3 and PC ... Richard Grodzik has designed an RGB Monitor Tester ... Robin Abbott returns with an Introduction to VDHL hardware development language ... the Barcode Reader is ready and waiting ... see you next year.

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Hewlett Packard 8754A (opt. H26) – 4MHz – 2.6GHz	£2950
IFR 7750 10KHz – 1GHz	£3250
Marconi 2370 – 110MHz	£995
Marconi 2371 – 30KHz – 2000MHz	£1250
Meguro MSA 4901 – 1-300GHz (AS NEW)	£1500
Meguro MSA 4912 – 1-1GHz (AS NEW)	£1995
Polrad 641-1 – 10MHz – 18GHz	£1500
Rohde & Schwarz – SWOB 5 Polyskop 0.1 – 1300MHz	£1800
Takeda Riken 4132 – 1.0GHz Spectrum Analyser	£2500
Tektronix 7L18 with mainframe (1.5-60GHz with external mixers)	£2000
Tektronix 495P – 100Hz – 1.8GHz programmable	£4950

MISCELLANEOUS

Adret 740A – 100KHz – 1120MHz Synthesised Signal Generator	£800
ANRITSU ME 462B DF/3 Transmission Analyser	£3000
Danbridge JP30A – 30KV Insulation Tester	£1500
Anritsu MG642A Pulse Pattern Generator	£1500
Dranetz 626 – AC/DC – Multifunction Analyser	£850
EIP 331 – Frequency counter 18GHz	£700
EIP 545 – Frequency counter 18GHz	£1500
EIP 545A – Frequency counter 18GHz	£1600
EIP 575 – Frequency counter 18GHz	£1750
Farnell AP70-30 Power Supply (0-70v/30A) Auto Ranging	£750
Farnell TSV-70 MKII Power Supply (70V – 5A or 35V – 10A)	£250
Farnell DSG-1 Synthesised Signal Generator	£125
Farnell ESG-1000 Synthesised Signal Generator 1GHz (as new)	£1650
Flure 5100A – Calibrator	£2500
Guildline 9152 – T12 Battery Standard Cell	£550
Hewlett Packard 331A – Distortion Analyser	£300
Hewlett Packard 3336C – Synthesised Signal Generator (10Hz – 21MHz)	£1000
Hewlett Packard 3437A System voltmeter	£350
Hewlett Packard 3456A Digital voltmeter	£850
Hewlett Packard 3438A Digital multimeter	£200
Hewlett Packard 3488A – Switch/Control Unit	£650
Hewlett Packard 35600A Dual Ch. Dynamic Signal Analyser	£3750
Hewlett Packard 3711A/3712A/3791B/3793B Microwave Link Analyser	£2250
Hewlett Packard 3325A – 21MHz Synthesiser/Function Gen	£1500
Hewlett Packard 3488A – HP – 1B Switch control unit (various Plug-ins available)	£650
Hewlett Packard 3455A 6½ Digit M/Meter (Autocal)	£750
Hewlett Packard 3478A – Multimeter (5½ Digit) + HP – 1B	£550
Hewlett Packard 3586A – Selective Level Meter	£1000
Hewlett Packard 3776A – PCM Terminal Test Set	£1500
Hewlett Packard 3779A/3779C – Primary Mux Analyser	from £600
Hewlett Packard 3784A – Digital Transmission Analyser	£4995
Hewlett Packard 37900D – Signalling Test Set (No 7 and ISDN)	£6000
Hewlett Packard 4262A – Digital LCR Meter	£1350
Hewlett Packard 4275A – LCR Meter (Multi-Frequency)	£3950
Hewlett Packard 4338A – Millionmeter (As New)	£2000
Hewlett Packard 4342A 'Q' Meter	£995
Hewlett Packard 435A or **B** Power Meter (with 8481A/8484A)	from £750
Hewlett Packard 4279A – 1MHz C-V Meter	£4500
Hewlett Packard 4948A – (TIMS) Transmission impairment M/Set	£1500
Hewlett Packard 4972A – Lan Protocol Analyser	£1750
Hewlett Packard 5420A Digital Signal Analyser	£350
Hewlett Packard 5335A – 200MHz High Performance Systems Counter	£600
Hewlett Packard 5314A – (NEW) 100MHz Universal Counter	£250
Hewlett Packard 5316A – Universal Counter (IEEE)	£500
Hewlett Packard 5183 – Waveform Recorder	£1750
Hewlett Packard 5238A Frequency Counter 100MHz	£250
Hewlett Packard 5370A – 100MHz Universal Timer/Counter	£450
Hewlett Packard 5384A – 225 MHz Frequency Counter	£650
Hewlett Packard 5385A Frequency Counter – 1GHz – (HP1B) with OPTS 001/003/004/005	£995
Hewlett Packard 6253A Power Supply 20V – 3A Twin	£200
Hewlett Packard 6255A Power supply 40V – 1.5A Twin	£200
Hewlett Packard 6266B Power Supply 40V – 5A	£220
Hewlett Packard 6271B Power supply 60V – 3A	£225
Hewlett Packard 6622A – Power Supply, Dual O/P	£1650
Hewlett Packard 6623A – Power Supply, Triple O/P	£1750
Hewlett Packard 6652A – Power Supply (0 – 20V, 0 – 25A)	£1250
Hewlett Packard 6264B – Power Supply (0 – 20V, 0 – 25A)	£400
Hewlett Packard 7475A – 6 Pen Plotter	£250
Hewlett Packard 7550A – 8 Pen Plotter A3/A4	£450

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Power Supply 20V-50A £450 ***Discount for Quantities***

Hewlett Packard 83555A – Millimeter – Wave source Module 33-50GHz	£4250
Hewlett Packard 8015A – 50MHz Pulse Generator	£750
Hewlett Packard 8405A – Vector Voltmeter	£350
Hewlett Packard 8165A – 50MHz Programmable Signal Source	£1650
Hewlett Packard 8350B – Sweep Oscillator Mainframe (various Plug-Ins available) extra	£2650
Hewlett Packard 8152A – Optical Average Power Meter	£1250
Hewlett Packard 8158B – Optical Attenuator (OPTS 002 + 011)	£1100
Hewlett Packard 8180A – Data Generator	£1500
Hewlett Packard 8182A – Data Analyser	£1500
Hewlett Packard 8350B – Sweep Oscillator Mainframe (various plug-in options available)	£2500
Hewlett Packard 83554A – Wave Source Module 26.5 to 40GHz	£3500
Hewlett Packard 8620C Sweep oscillator mainframe	from £250
Hewlett Packard 8656A – Synthesised Signal Generator (990MHz)	£2000
Hewlett Packard 8656B – Synthesised Signal Generator	£2950
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Hewlett Packard 8756A – Scalar Network Analyser	£1500
Hewlett Packard 8757A – Scalar Network Analyser	£2250
Hewlett Packard 8903A – Audio Analyser (20Hz – 100KHz)	£2600
Hewlett Packard 8903E – Distortion Analyser (Mint)	£2000
Hewlett Packard 8958A – Cellular Radio Interface	£2000
Hewlett Packard 8901A – Modulation Analyser	£3400
Hewlett Packard 8920A – R/F Comms Test Set	£6000
Hewlett Packard 8922b – GSM Radio Comms Test Set	£9995
Hewlett Packard P382A Variable Attenuator	£250
Hewlett Packard 1630D – Logic Analyser (43 Channels)	£650
Hewlett Packard 16500A – Fitted with 16510A/16515A/16530A/16531A – Logic Analyser	£4000
Hewlett Packard 11729B – Carrier Noise Test Set	£2000
Krohn-Hite 2200 Lin/Log Sweep Generator	£995
Krohn-Hite 4024A Oscillator	£250
Krohn-Hite 5200 Sweep, Function Generator	£350
Krohn-Hite 6500 Phase Meter	£250
Leader 3216 – Signal Generator (100KHz – 140KH`z) AM/FM/CW with built-in FM stereo modulator (mint)	£995
Marconi 2019 – 80KHz – 1040MHz Synthesised Sig. Gen	£1450
Marconi 2019A – 80KHz – 1040MHz – Synthesised Signal Generator	£1600
Marconi 2022A – 10KHz – 1GHz AM/FM Signal Generator	£2000
Marconi 2041 – (10KHz – 2.7GHz) Low Noise	£7500
Marconi 2305 – Modulation Meter	£1995
Marconi 2610 – True RMS Voltmeter	£850
Marconi 2871 Data Comms Analyser	£1000
Marconi 2955 – Radio Comms Test Set	£3000
Marconi 6960 – Power Meter & Sensor	from £950
Philips PM 5167MHz function gen.	£400
Philips 5190 L.F. Synthesiser (G.P.I.B).	£800
Philips 5193 Synthesised Function Generator	£1500
Philips 5518 Synthesised Function Generator	£1500
Philips PM5519 – TV Pattern Generator	£350
Philips PM5716 – 50MHz Pulse Generator	£525
Philips PM6652 – 1.5GHz Programmable High Resolution Timer/Counter	£900
Philips PM6673 – 120MHz High Resolution Universal Counter	£430
Prema 4000 – 6 ½ Digit Multimeter (NEW)	£450
Racal 1992 – 1.3GHz Frequency Counter	£800
Racal Dana 9081/9082 Synth. sig. gen. 520MHz	from £500
Racal Dana 9084 Synth. sig. gen. 104MHz	£450
Racal Dana 9303 R/F Level Meter & Head	£650
Racal Dana 9917 UHF frequency meter 560MHz	£175
Racal Dana 9302A R/F multivoltmeter (new version)	£375
Racal Dana 9082 Synthesised am/fm sig gen (520MHz)	£500
Racal 9301A – True RMS R/F Multivoltmeter	£300
Racal 6111/6151 – GSM Radio Comms Test Set	£POA
Rohde & Schwarz LFM2 – 60MHz Group Delay Sweep Gen	£1600
Rohde & Schwarz Scud Radio Code Test Set	£300
Rohde & Schwarz CMS 54 Radio Comms Monitor	£6250
Rohde & Schwarz CMTA 94 GSM Radio Comms Analyser	£7500
Schaffner NSG 203A Line Voltage Variation Simulator	£950
Schaffner NSG 222A Interference Simulator	£850
Schaffner NSG 223 Interference Generator	£850
Schaffner WSG 431 Electrostatic Discharge Simulator	£1250
Schlumberger 4031 – 1GHz Radio Comms Test Set	£4995
Schlumberger 2720 1250MHz Frequency Counter	£500
Schlumberger 7060/7065/7075 Multimeters	from £350
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Solartron 1250 – Freq. Response Analyser	£2500
Stanford Research DS 340 – 15MHz Synthesised Function (NEW) and arbitrary waveform generator	£1200
Systron Donner 6030 – Microwave Frequency Counter (26.5GHz)	£2500
Telequipment CT71 Curve Tracer	£250
Tektronix TM5003 + AFG 5101 Arbitrary Function Gen.	£1500
Tektronix 1240 Logic Analyser	£500
Tektronix DAS9100 – Series Logic Analyser	£500
Tektronix – Plug-ins – many available such as SC504, SW503, SG502, PG508, FG504, FG503, TG501, TR503 + many more	£POA
Tektronix AM503 + TM501 + P6302 – Current Probe Amplifier	£995
Tektronix PG506 + TG501 + SG503 + TM503 – Oscilloscope Calibrator	£1995
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Tektronix 577 – Curve Tracer	£1150
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Valhalla Scientific – 2724 Programmable Resistance Standard	£P.O.A.
Wandel & Goltermann PFJ-8 – Error/Jitter Test Set	£12500
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Wayne Kerr 4225 – LCR Bridge	£600
Wayne Kerr 6425 – Precision Component Analyser	£275
Wayne Kerr 8905 – Precision LCR Meter	£850
Wavetek 171 – Synthetised Function Generator	£250
Wavetek 172B Programmable Sig Source (0.0001Hz – 13MHz)	£P.O.A.
Wavetek 184 – Sweep Generator – 5MHz	£250
Wavetek 3010 – 1-1GHz Signal Generator	£1250
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